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NOTES ON INSTRUMENTS

BEST SUITED FOR ENGINEERING FIELD-WORK

IN INDIA AND THE COLONIES

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IN INDIA AND THE COLONIES

BY

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PREFACE.

THE Author is greatly indebted to Mr. BENNETT BROUGH's well-known work on Mine Surveying, from which several extracts have been made; and further desires to record his obligations to 'A Handbook for Surveyors,' by Messrs. Merriman and Brooks (an excellent little work on this subject, from which the tables of Stadia Reductions given in the Appendix are taken), and for the tables selected from Trautwine's well-known Pocket-Book—as being in more handy form than those in other works.

His thanks are also due to the following mathematical instrument makers, who have kindly lent their blocks :—

L. P. CASELLA, 147 Holborn Bars, E.C.
T. COOKE AND SONS, 8 Victoria Street, S.W., and at York.
J. DAVIS AND SONS, All Saints' Works, Derby.
W. H. HARLING, 47 Finsbury Pavement, E.C.
J. LETCHER, Truro.
W. F. STANLEY, Great Turnstile, W.C.
TROUGHTON AND SIMMS, 128 Fleet Street, E.C.
NEGRETTI AND ZAMBRA, 138 High Holborn, W.C.

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NOTES ON INSTRUMENTS

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CHAPTER I.

INSTRUMENTS FOR HORIZONTAL ANGLE SURVEYING.

THIS work is compiled with the object of introducing new instruments and methods of work so as to facilitate the operations of the engineer in India or the Colonies. It is not the intention of the Author to treat the subject of surveying, *ab initio*, as in a text-book; the readers are supposed to be already conversant with the use of instruments in ordinary practice. Methods of work in the field and plotting the results, will, however, be dealt with in measure, mainly with the view of affording a useful reference for those who, as is often the case in India, are suddenly put on survey work of a description, of which they have previously had but a slight practical acquaintance.

The new instruments it is proposed to introduce to notice, will be described and illustrated, and the improved labour-saving methods of surveying with the tacheometer, detailed. The subject of rapid levelling for

reconnaissance work and road tracing will be handled in the same way. And to enhance the utility of the work, tables of stadia reductions, traverse multiplicands, and various others, are introduced in the Appendix.

In countries outside Europe, the conditions or external circumstances met with, in carrying out engineering field-work, differ essentially from those in England. In one direction, work is simplified by the general absence of hedges, roads and buildings, while in the other, the surveyor has to encounter difficulties inherent in a new or undeveloped country. Tracts of dense forest or scrub have to be penetrated, broken country negotiated, without the aid of any but rough inaccurate maps, and often in the complete absence of any such helps. The difficulties met with in working under such untoward conditions are well shown in 'Railway Surveying in Tropical Forests,' a paper contributed by Mr. Shelford, A. M. Inst. C.E., to the Minutes of the Institution, vol. cxxxiii., and containing much valuable information, portions of which will be quoted *in extenso* in this work.

In England all engineering field operations are carried out by practically two instruments only, the theodolite and the level. To these may be added in India, the prismatic compass. In a country of limited extent, whose area is thoroughly well mapped, and where so many salient landmarks exist in the landscape —as church spires, prominent buildings, &c.—lines of traverse can be run without the aid of the magnetic

compass, an instrument of which little use is made. In the Colonies, America and India, on the other hand, where vast unmapped areas are necessarily met with, the use of the needle is absolutely indispensable. In America the instruments used are adapted to the requirements of the country.

The American Transit, built by Messrs. J. Davis and Son, Derby, shown in Fig. 1, carries a dial, which is of large size and quite accessible to observation. In English-made theodolites, on the other hand, *vide* Fig. 2, the compass dial is generally omitted altogether, except in the form of an attachable box-compass, whose functions are limited to showing the magnetic meridian, and that only by aid of a hand-compass, or else, where a dial is supplied, it is of small size, minutely divided, and so hedged in by the telescope standards and various other parts, as to be unapproachable to close observation, and thus is practically useless. An instrument of this description is plainly unsuited for engineering reconnaissance field-work in the Colonies. For accurate map-making, as performed by professional surveyors and for final railway alignments, the transit cannot be surpassed; but for all other classes of work it is, for several reasons, decidedly inferior, in simplicity of construction, rapidity, and even accuracy of work, to other forms which will be described.

Invention as regards above-ground surveying instruments has been, in fact, absolutely at a standstill for a long time, if the refinements of stadia measurements and theodolite levelling, which are mostly practised on the Continent and in America, be excluded.

In Indian practice, the instrument most common in use is the prismatic compass, which reads to a half or at

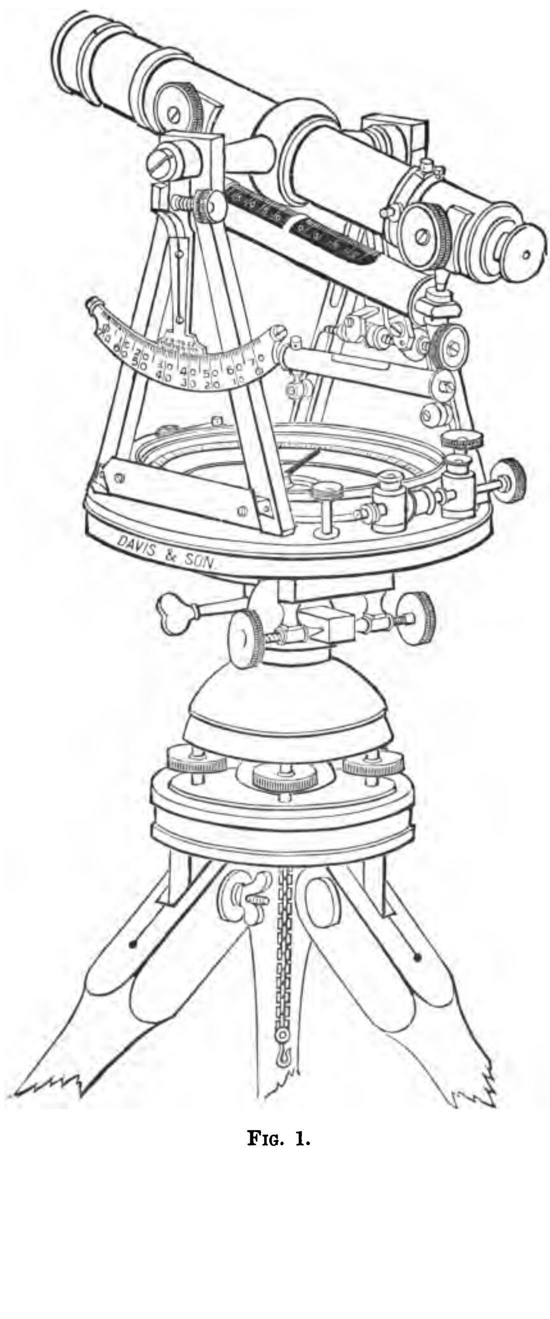


Fig. 1.

most one-third of a degree. It is reasonable to assume that some instrument, intermediate in precision—from

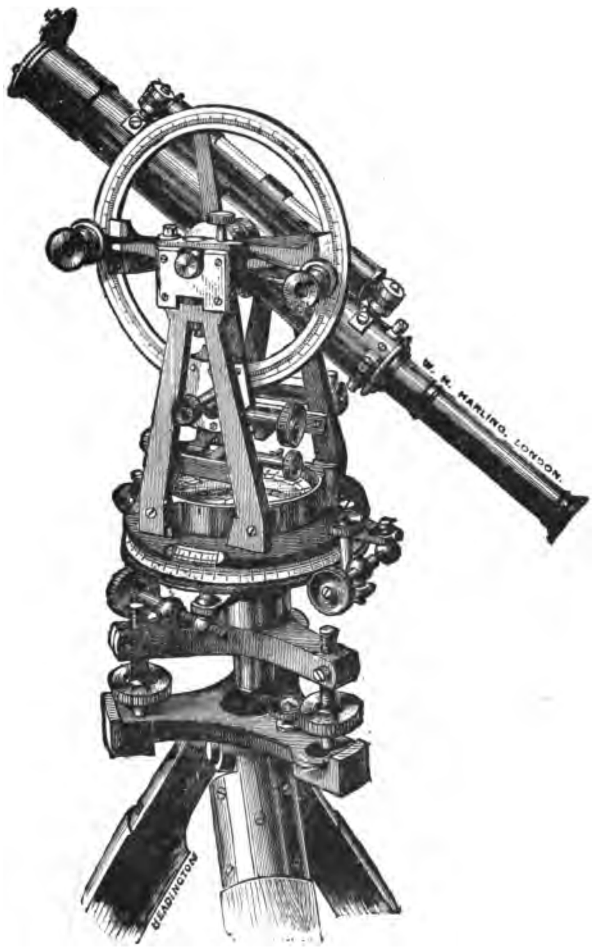


FIG. 2.

the prismatic compass, which reads degrees, to the theodolite, which reads to single minutes—would supply a distinct want. To satisfy these requirements, it will

be only necessary to revert to designs of instruments used for mining work. Here we find that invention has been by no means stationary, but that the original simple miner's dial has been again and again improved upon, till it has now been developed into an instrument, which is eminently suited for above- as well as below-ground work. In an unmapped country the con-

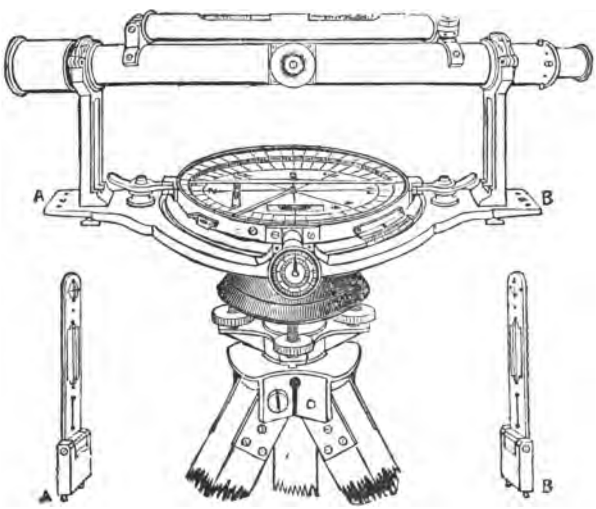


FIG. 3.—DAVIS'S IMPROVED HEDLEY DIAL, WITH TELESCOPE AND SIGHTS, AND HOFFMANN PATENT JOINT.

ditions closely approximate to those in a dark mine, or a ship at sea, consequently the magnetic needle must play an all-important part in any instrument suitably designed for Colonial work.

The construction of all mining dials differs radically from that of the theodolite, in that the dial itself forms the most prominent part, and is kept free from obstruction by adopting a different method of fixing the

telescope (*vide* Fig. 3). Side standards are dispensed with, and the telescope is mounted (as in a level) on uprights, which in the higher forms are carried by a rocking centre, or what are technically termed gimbals, the pivots of which are at the side below the dial, so that no obstruction is afforded to a close observation of the bearings. In plain sight instruments, the sight vanes take the place of the telescope supports, and the dial is quite open to view. Another point in favour of the mining dial, is simplicity of form and consequent ease of manipulation. The screws for racking, clamping, and micro measurements, are all situated out of the way below the body of the instrument, and although not openly exposed, are easily found with a very little practice without fumbling. Magnifying vernier readers, always a source of delay and annoyance, particularly in hot countries, are not required; the verniers which subdivide to three minutes, are quite distinct, and can be rapidly read off by the unaided vision. The same applies to the vertical arcs.

A comparison between the Davis improved dial, shown in Fig. 3, with the English transit theodolite in Fig. 2, will demonstrate the point of the above remark.

Secondly, as regards accuracy of working. In all vernier dials, the needle can be made to act in a more or less degree as a check to the accuracy of the meridian angles taken by the vernier, which is not the case with the theodolite, a purely azimuth instrument, any angular errors being liable to be carried through the whole traverse. The minuteness of reading in dials (three minutes) is amply sufficient for all engineering pre-

liminary operations—in fact, as a rule it is in advance of actual requirements.

Preliminary surveys in India are generally carried out by sub-overseers, a low-paid class of native subordinates who could not be entrusted with so com-

FIG. 4.

plicated an instrument as a theodolite. But they could easily be got to work vernier rack dials, which are very strongly built instruments, capable of standing rough treatment without injury, and superior in every way to the prismatic compass.

The prismatic compass (Fig. 4), taken from Messrs. T. Cooke and Son's catalogue, is by no means devoid of good points. These are: Simplicity of construction; the ease with which magnified readings of a minutely divided scale are read; lightness; and cheapness. Its demerits are: (1) Its delicacy and consequent liability to get out of order—this is inherent in the strain thrown upon the pin, from having to support the weight and leverage of the rim. (2) The space separating the prism and fore-sight vane is limited to the diameter of the box, which cannot well exceed four-and-a-half or five inches, thus giving a short guide to the line of sight. (3) Only fore-sights can be taken, thus the instrument has to be turned right round and a fresh reading made for a back-sight, a defect from which all plain sight dials are free. (4) No levels are supplied, so that inexperienced observers are apt to tilt the box so as to foul the needle. (5) The line of sight being fixed in a horizontal plane, objects, much above or below this plane, cannot be seen without recourse to the reflecting mirror, which is not easy to adjust, and hence its use is generally altogether neglected.

The Author has devised a modification of the prismatic compass, in which all the disadvantages just enumerated, with the exception of the first, are eliminated. Figs. 5 and 6 are representations of this instrument, which was made by Mr. W. H. Harling, London. It is termed the Combined Prismatic Dial and Clinometer.

The compass-box, of $4\frac{1}{2}$ inches diameter, is pivoted on a rocking centre, which carries two sight vanes, pro-

vided with double vertical sights of the alternate slit-and-hair type common to all dials, so that sights can be taken fore and back, without having to revolve the instrument 180°, as is the case with the ordinary

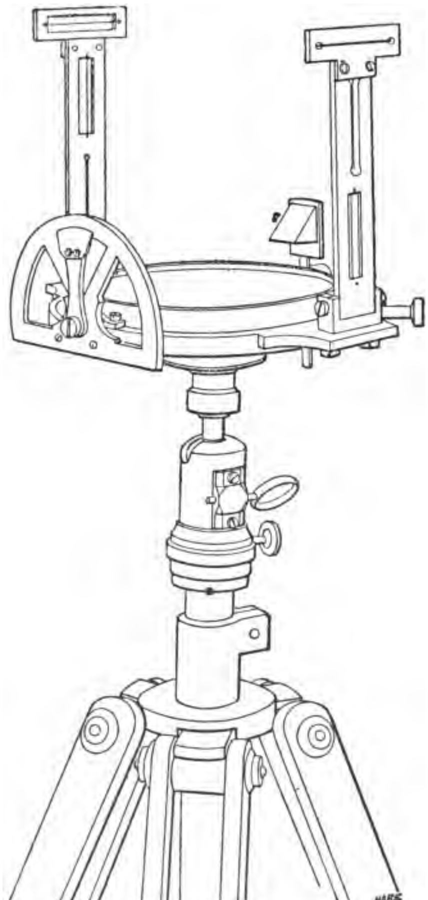


FIG. 5.

prismatic compass. The prismatic reader is placed on the left side, and on the right, a vertical semicircular

graduated arc is fixed to the side of the rocker. This arc is graduated to single degrees, and the angle is read with sufficient precision, by means of an upright pointer,

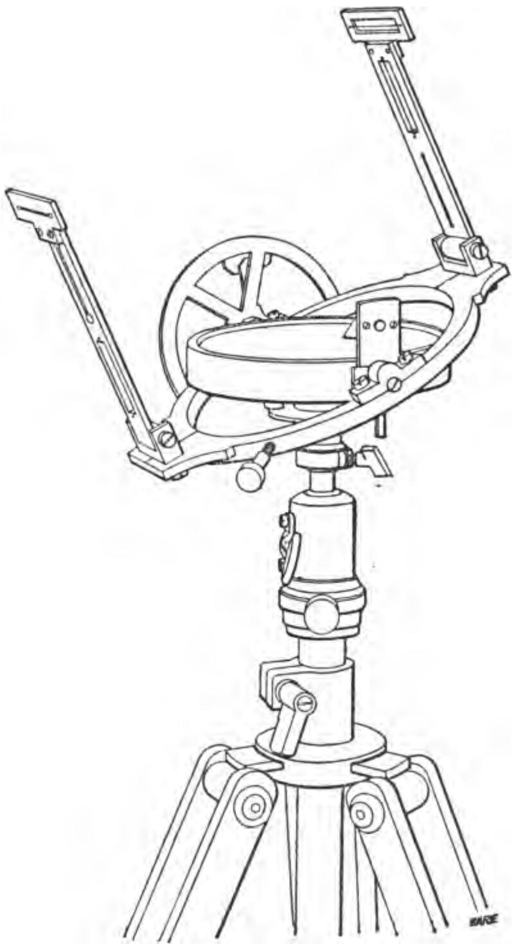


FIG. 6.

carrying a vernier reading to five minutes. The compass-box contains two fixed spirit-levels at right angles to

each other, the one in the direction of the line of sight being longer than the other.

A further development in this instrument, consists in the introduction of long horizontal sights, fixed on top of the vertical sight vanes. These are exactly similar to the vertical sights, and are equally effective and far superior to the ordinary small circular openings with cross wires, usually provided for this purpose.

In order to increase the range of utility of this instrument, by rendering it capable for use as a clinometer or road tracer, it is provided with the novelty of a vertically adjustable base.

The compass itself is mounted on an ordinary ball-and-socket dial joint. This joint is not carried direct on the tripod, but is screwed on top of a smooth brass hollow vertical rod. This rod passes through a vertical socket formed in the tripod head, and is capable of being easily moved up and down by hand, carrying the instrument with it, and can be secured by a powerful clamp in any desired position. At the base of the vertical rod, which is twelve inches long, is a hook on which a brass chain hangs, at the extremity of which is a round disc. This chain is of a fixed length, such that the vertical distance from the horizontal line of sight on top of the vanes to the base of disc, is some known length in feet—in this case four feet.

Where road tracing or contouring is required to be done, a T staff, four feet long, will be used, and by means of the adjustable rod, the instrument can always be placed, no matter how the tripod is set up, at the exact required height above peg. When only the vertical

sights are used, as in surveying, the adjustable rod is not shifted at all. These additions render the instrument adaptable for purposes far beyond that of the ordinary compass, and that at a very small additional cost.

The price of this instrument, made by Harling, is 12*l.* 10*s.*

Mr. Shelford, to whose work on 'Surveying in Tropical Forests' allusion has already been made, does not favour the prismatic compass, as the following excerpt will show :—

"In the Honduras and all the African surveys the trade route or path was surveyed with a miner's dial, chain, and spirit level, and from the base thus obtained cross sections were cut and surveyed in a similar manner to the base itself. To produce the plan of the base, a traverse is run along the road by taking angles from the magnetic north. A theodolite survey of the road would be most laborious and liable to errors, which would be multiplied throughout the whole survey. For this traverse the miner's dial is used. The Author has found it the most expeditious instrument for producing a plan of the road, and the particular form shown (in Fig. 7) is the simplest.

"It is the well-known North Country dial mounted on solid mahogany legs. It has a compass needle swinging on an agate pivot over a fixed card graduated from 0° to 360°. It is fitted with a ball-and-socket joint with a clamp, and has only to be roughly levelled by hand. The sight line is marked by wires in the usual way. This instrument in proper hands gives excellent results and is very fast. A reconnaissance

survey with it, when checked by a theodolite survey, made over a staked-out railway in West Africa, showed an error of about one chain in twenty miles. The instrument costs about 6*l.*, and its great advantages are speed, lightness, portability, and, above all, comparative immunity from accidents. It will stand severe treatment, to which instruments are subjected in rough countries, when a more delicate instrument would be ruined. Furthermore its low cost enables several to

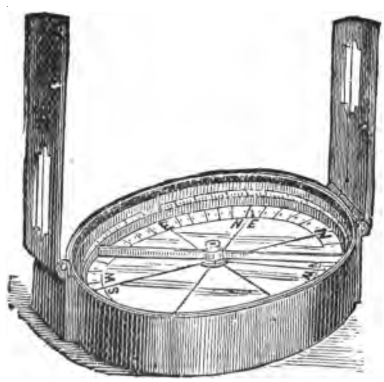


FIG. 7.

be carried. The Author has never found a prismatic compass satisfactory. In hot damp countries it becomes foul and slow in action, and it is apt occasionally to give a false reading by the dial touching the top glass when being read several hundred times a day. Errors of reading the dial and the disturbing influence of neighbouring ironstone are counteracted by invariably taking the bearing of each line from each end, that is by taking a fore-sight and back-sight on each line."

The dial used by Mr. Shelford is now hardly made at all, except as a pocket dial, an illustration of which is given in Fig. 7. This is really a very inferior instrument, reading only to degrees, and the extraordinary accuracy of the result must be put down to the errors unavoidable with so rough an instrument, tending to correct themselves. The sights taken were probably

Fig. 8.

very short; similar accuracy would be impossible with long sights over open country. A much better instrument provided with spirit level and a long interval between the sight vanes is shown in Fig. 8.

This dial is manufactured by Mr. W. H. Harling. This class of dial with rigid sights is very well suited for work in flat country, where readings to one degree are sufficient in exactitude, but a great improvement is

effected, when a revolving vernier is supplied. This considerably increases the cost, which is very little less

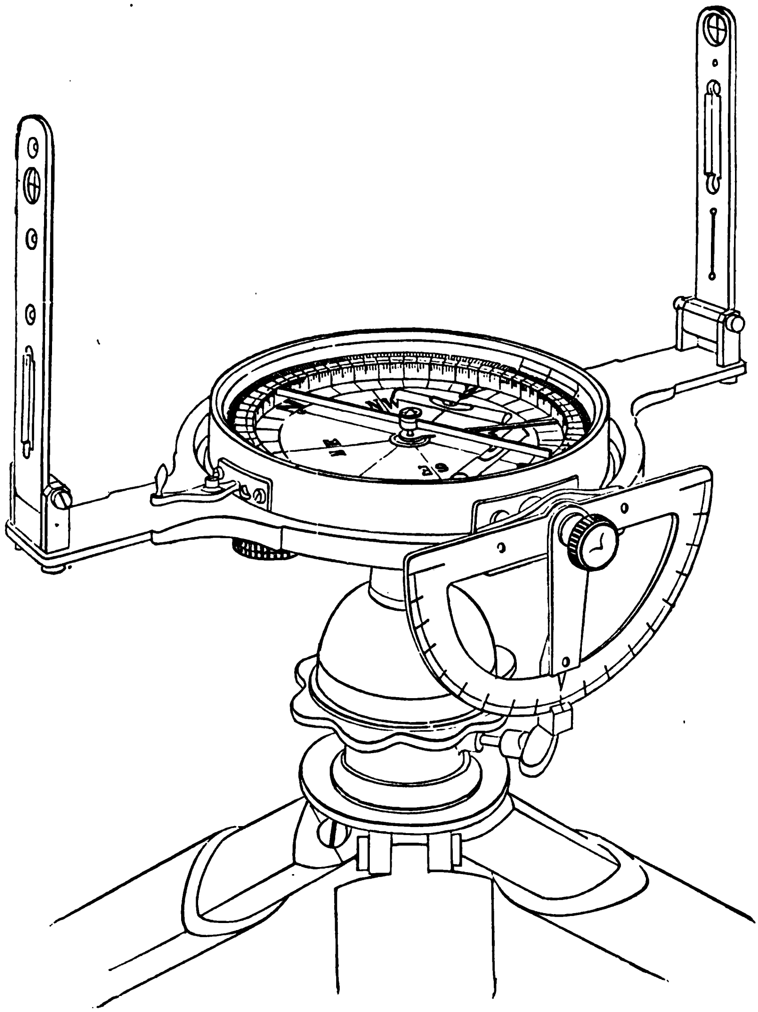


Fig. 9.

than that of the next stage of improvement, so that the rigid dial with vernier may be considered as quite

obsolete. This further improvement is effected by the addition of a rocking centre, at the ends of which the sight vanes are fixed. Figs. 9, 10 and 11 will serve to explain the construction of this instrument, which is termed the Hedley Rack Dial. This pattern was first introduced as long ago as 1850 by Mr. John Hedley, Government Inspector of Mines, in collaboration with the late Mr. John Davis, the founder of the well-known

Fig. 10.—Rack Dial, by Harling.

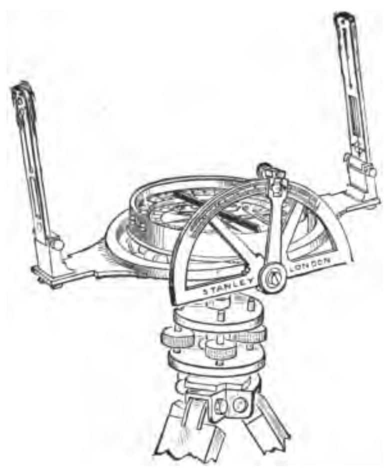


Fig. 11.—Rack Dial, by Stanley.

firm of John Davis and Co., Derby, by whose enterprise most of the improvements in miners' dials originated.

This dial is supplied with a detachable graduated vertical side arc, which gives the angle of inclination of surface of ground and also the deductions per centum in the length of lines measured on the slope. The vernier, which reads to three minutes, is inside the box; consequently this form is best suited to work with plain sights and without a telescope, which is bound to some-

what hinder the free view of the dial face. The principles of construction and graduation of these dials will be dealt with in later chapters. The clamping screws and milled head for operating the rack, which moves the vernier when the lower limb is clamped, lie below the dial box, and are easily found. There are no tangent

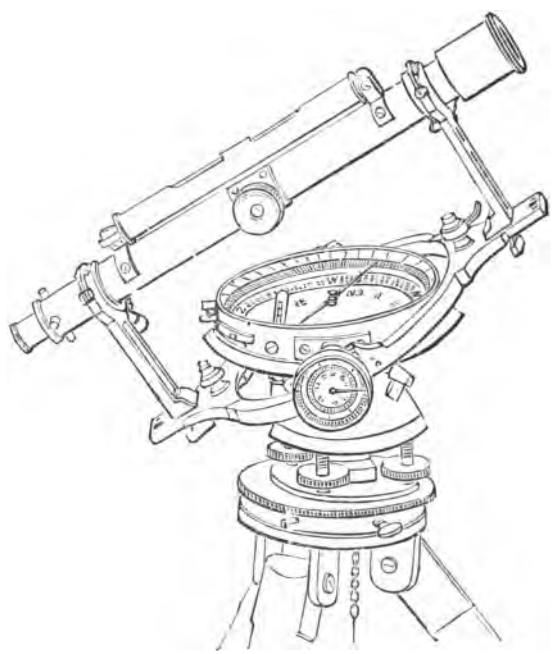


FIG. 12.—IMPROVED HEDLEY DIAL, BY DAVIS.

screws; and they are not required, as the rack pinion motion enables the instrument to be easily and accurately aligned in any direction or at any angle. The simplicity of this instrument, and the absence of complication in its construction commends it for use by native surveyors, or generally as a very superior substitute to the ordinary prismatic compass. It is not heavy, packs

up into a very small case, and being of solid make will stand much rough usage with impunity. It is illustrated in Figs. 9, 10 and 11.

The final improvement of the rack dial is termed the Improved Hedley. It is very similar in appearance to the last type, but is even more rigidly built. The

FIG. 13.—IMPROVED HEDLEY DIAL, BY DAVIS.

Davis form is illustrated in Figs. 3, 12 and 13. The improvement consists mainly, in the vernier being attached to the outside of the compass, instead of within it as in the previous example. In this position the vernier is read with greater ease, the necessity of raising the head over the compass-box being obviated.

There are thus two graduated circles instead of

one as in the ordinary fast needle rack dial, and the mechanism is modified so that the vernier and needle readings correspond, forming a mutual check.

The vertical side arc in Fig. 9 is dispensed with in some forms, a small circular box dial being substituted,

FIG. 14.

in which the pointer is actuated by cog-wheels and covers an exaggerated length of arc, and by this device marks plainly to single degrees, which from the small diameter of dial—1¾ inches—it would otherwise be unable to effect.

Figs. 14 and 15 represent other types of the Improved Hedley. The former is made by Mr. Letcher, of Truro, and the latter by Mr. W. F. Stanley, London. In the latter the vertical arc above the dial is retained in preference to the box dial. The pivot of the arc being below the compass-box, it interferes very little with a free view of the dial. The side arc (Fig. 9) has

Fig. 15.

always the disadvantage of being in the way of the hands, in the operations of levelling up or adjusting the instrument. The arc pointer in Fig. 15 is provided with a clamp to fix the instrument at any desired inclination. An arc of this description is in appearance (though not in reality) more exact than the compacter form common to Davis's and Letcher's dials.

To obtain the utmost utility from an instrument of this description it should be capable of being fixed at any desired quarter degree in the vertical arc, so as to be available for rough levelling operations, if ever so required. A more minute reading than five minutes (which can be read with the naked eye) is, in the Author's opinion, decidedly superfluous and disadvantageous.

Stanley's dial as illustrated in Fig. 15 is a very good instrument, but could in the Author's opinion be improved by the addition of a rack on the outside of the vertical semicircular arc, and a vernier on the pointer to read to three or five minutes. The same remarks would apply to the Davis dial (Figs. 3, 12 and 13), to the other axle of which a semicircular vertical arc with rack and pinion and vernier to pointer could easily be fixed. This should be detachable at will, the box dial—an admirable contrivance—being retained as a fixture for ordinary purposes, the additional arc being mounted on the opposite side for tacheometrical or levelling purposes, for which the box circle is not sufficiently precise.

It will now be advisable to advert to the principles governing the design of the various kinds of instruments already in part described.

The Prismatic Compass is of similar construction to a ship's compass, in that the graduated rim or card is attached to the needle and remains stationary pointing to the north. The graduations of the rim are from zero to 360 direct, i.e. west to east. The line of sight is marked by a projecting pin on the box for back-sight and the hair in fore-sight. This pin revolves with the

box case round the graduated rim, and the reading of the rim at the pin gives the bearing or meridian angle, i.e. the azimuth between the line of sight and the north point. In the case of the prismatic compass, the pin and reader being placed at the back-sight, if the zero of the rim were at the north point and the graduations to count round from west to east, the readings would be back readings, or 180° greater than the fore-bearing. To obviate this a false graduation is adopted, the zero being placed at the south point when the fore-sight is directed north.

The case of common dials is different. Here the graduated circle is not attached to the needle but is part of the movable box. Hence when the sights fixed to the box are turned, the graduated circle moves round, and the needle will not read the actual, but the *reverse* departure. In all such cases the dial should be graduated reverse, right to left, i.e. from north to west. If this be done, true bearings will be read. If, on the other hand, the graduated circle be numbered in degrees in the usual way, north to east, the readings taken will have to be plotted with a reverse protractor, or else a correction made, by deducting each false reading from 360°.

In vernier Hedley dials the principle of the construction of the instrument, though in appearance quite different, is practically identical with that of the theodolite. There is a lower limb comprising a vertical axis and a horizontal graduated circle. There is also a vernier plate which, when the lower limb is clamped, revolves round the horizontal circle of the lower limb, carrying the sight vanes or telescope standards with it.

In the ordinary Hedley rack dial, Fig. 9, the vernier is fixed to the inside of the rim of the cover of the box, and overlaps the horizontal graduated circle, which is an annular rim raised above the floor of the box, graduated direct from 0° to 360°. The needle plays within this sunk circle just clear of its edge. The zero of the vernier is fixed exactly in the line of sight, between the two sight vanes. If this zero be made to coincide with that on the horizontal circle, and clamped, and the vertical axis collar unclamped, and the zero of both brought up to the north point indicated by the needle, then the instrument is in a position to take meridian angles. The axle collar clamped and the vernier loosed, a milled head, projecting below the bottom of the compass-box, actuates a pinion which travels on a hidden rack fixed round the outer circumference of the stationary horizontal circle, and moves the vernier plate, together with the rim of the compass-box and the sight vane gimbals, which are pivoted to, and rigid with the outer circumference of the box. The horizontal circle (which is part of the lower limb) remains fixed, and the needle also. Hence, when meridian angles are taken, the needle remains fast at the north point. If upper and lower limbs are clamped together and the vertical axis loosed, the lower limb carrying the graduated circle revolves round the needle; the conditions then are the same as in the rigid dial, the bearings read at the end of the needle being false, and requiring to be subtracted from 360° to give the real bearing of the sight line. This is inseparable from there being only one horizontal circle, read by both vernier and needle.

In the theodolite with dial the conditions somewhat differ. Here, as in the rack dial, the vernier plate revolves round a fixed horizontal circle, but the dial has a separate graduated circle of its own, which forms part of the upper, not the lower limb, and hence revolves concentrically with the vernier plate. This dial is graduated the reverse way, the east point being marked at the west, and *vice versa,* hence the readings of the vernier on the horizontal circle and the needle on its dial correspond. To effect the same arrangement in the dial, the firm of Davis and Son, as already mentioned, introduced their design of an improved Hedley dial (Fig. 3), in which the principle of the theodolite, inducing correspondence in the double reading of the dial and the vernier, was effected by adopting a second graduated circle outside the box, read by the vernier. The graduated circle inside the box is not, as in the former case (Fig. 9), attached to the lower limb, the rim carrying the vernier and sights only revolving, but as in the theodolite the whole box forms part of the upper or vernier plate, and the rack turns both simultaneously. The outer fixed circle is graduated reverse way, and the dial circle direct, consequently readings on both correspond. This same result is effected in the theodolite, but in this case the outer circle is graduated direct, the compass reverse. For some reason in connection with mining work, which is not understood, the dial is graduated direct. Thus true bearings are not read, but reverse bearings, necessitating the use of a reverse protractor. This is a distinct demerit, and in ordering these instruments the direct graduation of the outer circle and re

verse of the dial, as in a theodolite, should be insisted on. This of course does not apply to the old form (Fig. 9), which gives true bearings when the vernier is used.

The advantage of this form over the older is that readings can be taken from the vernier and also from the needle, and thus the liability of error is minimised. Any discrepancy at once detects either an error in reading, or a movement of the lower part of the instrument. With the fixed needle the latter is checked, but not the former.

The improved Hedley rack, having to move a heavier weight, is provided with larger teeth, and consequently is not so closely accurate in adjustment as in the older form; hence tangent screws have to be supplied to both upper and lower plates as in a theodolite. This detracts from the simplicity of the older instrument, which is unsurpassed in this respect, and hence is deemed more suitable for use by native surveyors than the improved type.

In construction the Davis improved Hedley is much more rigid; the rocking centre, instead of consisting of a flat plate, is of reversed U section, provided with two deep flanges. There is no reason why this should not be applied to the inner vernier older form, and no doubt could be so. The older form has the distinct advantage of being simpler. The native subordinate will not trouble to notice the double-dial reading, but the divergence of the needle from the north point, would be much more likely to attract his attention; hence the Author considers that for plain sight surveying, the older form with improved construction of rocking centre and box

vertical arc, is distinctly preferable to the new form, or even as it stands, without these minor improvements.

Another form of dial is Henderson's, made by Mr. Letcher, of Truro, illustrated in Figs. 16 and 18. In this the vernier plate consists of a diagonal piece

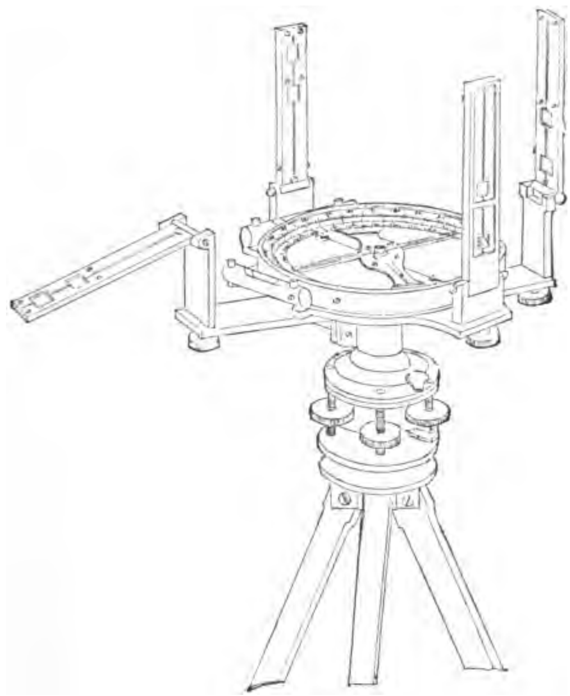


FIG. 16.

screwed inside to the bottom of the dial box, and provided with a large vernier at each extremity. The bottom of the dial box in all cases is part of the lower limb. Hence when the latter is clamped, both vernier and needle are stationary. The raised graduated rim is read as before by the needle, whereas a second circle

concentric to it, and flush with the flat bottom of the box is read by the verniers. Both these graduated circles are in one piece, and revolve together round the fixed circular base of the box, carrying the rim of the box and attached sight gimbals with them. From this arrangement it is clear that both readings must correspond. To prevent confusion, the graduations are similar in direction but have different starting points, the vernier diagonal lying east and west. To give true bearings, both graduated circles are reversed in direction and east and west points transposed. In this dial *alone*, owing to the reverse graduation, when the needle is used by itself, true bearings are read. This form is undoubtedly a good one, but must be classed as inferior to the outside vernier, which allows a larger diameter for the horizontal circle, being exterior, in lieu of interior, to the dial circle. The Henderson dial is very expensive, costing 28*l*.

A still further development of the mining dial is illustrated in Figs. 17 and 18. The former represents Stanley's mining theodolite with patent cranked gimbals. This is a high-class instrument, quite equal, and in some points decidedly superior, to a plain theodolite. The cranked gimbals clear the two ends of the dial box, so that the outside verniers are located here and not at the side, and the telescope can be inclined to 50° in each sense.

The graduation of this instrument (Fig. 17) as well as Stanley's improved Hedley (Fig. 15), is the same as in theodolite, i.e. as it should be.

The curved form of the rocking centre is a much

stronger and stiffer construction than the ordinary straight one with vertical uprights, and enables the telescope to be carried high above the dial. For aboveground operations, the circular vertical arc is hardly

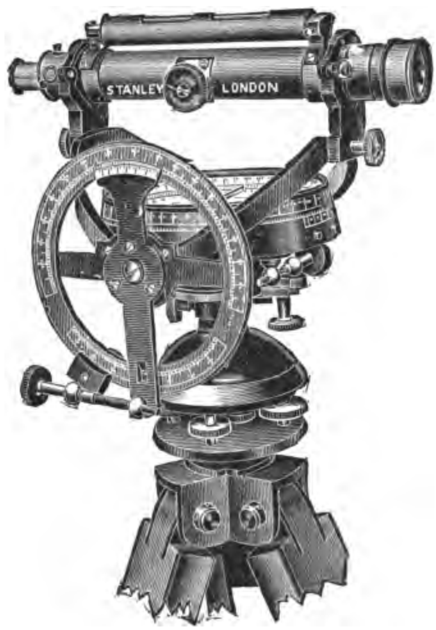


FIG. 17.

required, and for these purposes it is deemed that the design of the instrument would be improved, by changing it for a semicircular one, as in Fig. 15, but retaining the vernier with rack, instead of tangent screw (the whole circle greatly interfering with the manipulation of the Hoffmann head). The telescope should be as large as possible, and be fitted with an anallatic lens with stadia lines. The instrument would become a tacheometer as well as theodolite, and be useful for any

purpose, including levelling. The large dial gives it a distinct superiority over the ordinary form of theodolite tacheometer. The design thus modified is strongly recommended. For ordinary work, excepting theodolite levelling, where a vernier to vertical arc is indispensable, but including distance measuring, the Author prefers the simpler forms shown in Figs. 12 or 15.

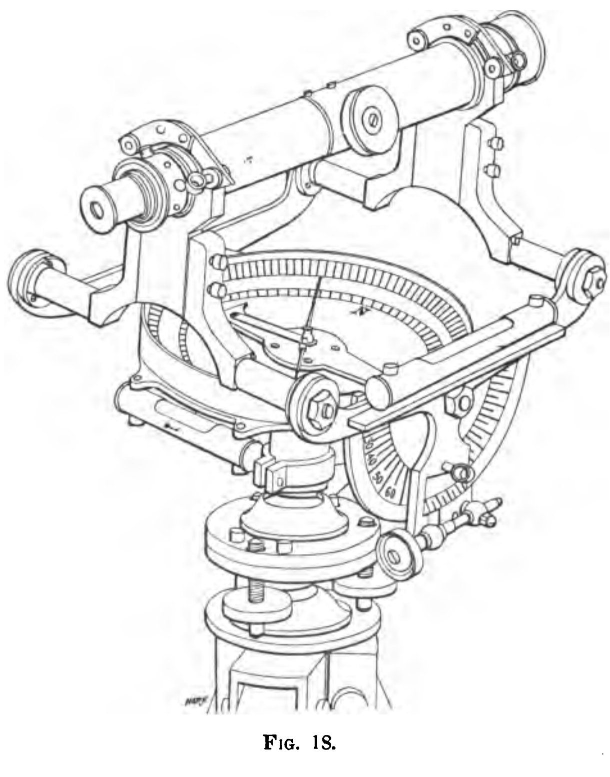


FIG. 18.

Fig. 18 illustrates Letcher's mining theodolite, in which a further novel development of the ordinary form of rocking centre is shown. The instrument, as shown in the illustration, is provided with a semicircular side

arc read by a vernier, and provided with a tangent screw. The arc is stowed out of the way below the dial, and the levels, which are of large size, are carried one on the rocking centre, and the other is attached outside the dial box. The arrangement adopted offers a remarkably clear view of the dial, which is most essential, as the vernier is inside the compass-box. The design of the dial is identical with that shown in Fig. 16 and already described. This form, though doubtless possessing many excellences, is not considered to be so suitable for above-ground work as Figs. 12, 14, 15 or 17, which have outside verniers, although from its construction, it may be a more precise instrument than the former two types, and its graduations give true—not reverse, meridian angles; it is also much more expensive.

As has been already observed, for all ordinary and preliminary operations the Improved Hedley (Figs. 3, 12, 14 and 15), if properly graduated, is undoubtedly superior to the theodolite or transit. Where tacheometrical levelling is required, or lining out work in deep excavation, form Fig. 17, Stanley's mining theodolite with anallatic telescope, is best adapted, and for an all-round precise instrument is unsurpassed. For *railway* final alignments, on the other hand, the transit theodolite must remain *facile princeps.*

The mounting of dials was formerly effected by a ball-and-socket joint, illustrated in Fig. 8, but for the better class of instruments, which are of some weight, and from their length possess considerable leverage, this joint is deficient in the requisite rigidity when

clamped. The Hoffmann joint, or Davis's modification of it, may be considered as decidedly superior, and is not much more expensive.

The following description of this joint is an excerpt from Mr. Bennett Brough's valuable work on mine surveying :—

"The miner's dial is usually fitted to a slightly conical spindle having on its lower end a ball, which is confined in a socket in such a way that it can be moved in any direction in the operation of levelling the instrument. The ordinary form of tripod has the disadvantage, that it is almost impossible to level up a sensitive bubble, so that it will remain in the centre of the rim, long enough to take a satisfactory sight. On levelling the instrument and sighting, a second glance at the bubble almost invariably shows, that it has changed its position, and it is necessary to level up again. This defect is due to the fact, that the levelling screws when moved in or out to a considerable extent, do not stand perpendicular to the plate on which they rest, but on an inclined plane, so that on turning them their points have a tendency to slide down the plane. In this position they spring, and turning is apt to bind or bend them. Another imperfection in many tripod heads is that the plummet is attached to some point on the axis, above or below, the centre of the ball or socket. In either case the plummet, after being set over a station, will, during the operation of levelling up, travel away from the point in a degree proportionate to the distance of the attachment of the plummet over the centre of the ball, and the deviation of the axis from the perpen-

dicular at the time the instrument is placed over the centre. The Hoffmann joint is free from these defects, as from its construction it is impossible for the plummet not to be perpendicular to the axis of the instrument. The advantages claimed for the Hoffmann tripod head are as follows: (1) A saving of one-half to two-thirds of the time usually occupied with screwing and unscrewing on the old plan; the instrument can be levelled approximately without the use of the screws; less than half a turn is then necessary to bring the instrument to a perfect level, the operation at the same time clamping it. (2) The levelling screws are at all times perpendicular to the plate to which they are attached, and to the plate and screw cap on which they rest. (3) The levelling screws are reduced in length, and their length and their duty to a minimum, the instrument being no higher nor heavier than before. (4) The shifting head for plumbing over a fixed point, an improvement common to all first-class instruments, is retained, and no extra screws are required to clamp the instrument. (5) The levelling screws are covered from dust, and at the same time are no obstruction to the working of the instrument in any position in which it can be placed."

The ordinary Hoffmann joint with levelling screws is shown in Fig. 3, and with sliding motion for precise adjustment over peg in Figs. 1 and 12.

Details are shown below in Fig. 19, taken from Davis's catalogue.

Davis's modified Hoffmann joint for dials where extreme accuracy of level is not absolutely essential, as in those without telescopes, is shown in Fig. 20. In

this the levelling screws are altogether dispensed with, the clamping being performed by a single turn of the milled flange marked A. This joint is manipulated with great ease and rapidity, and is strongly recommended in Mr. Bennett Brough's work. It is shown attached to instrument in Figs. 9 and 13. Its rubbing surface being ten times greater than in the ball-and-socket joint, it is far more rigid, and hence more suitable for heavy instruments.

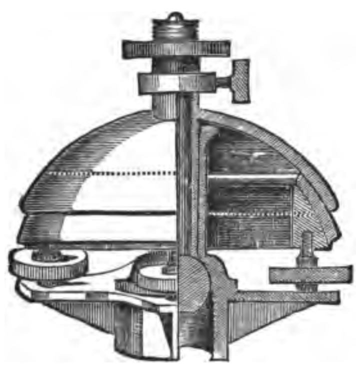


Fig. 19.

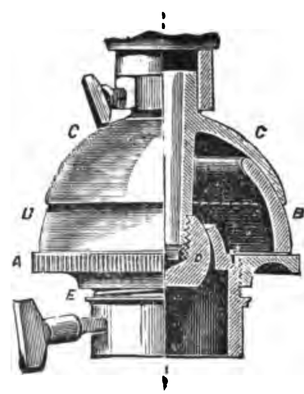


Fig. 20.

A résumé of the foregoing descriptions of different kinds of magnetic surveying instruments would not be out of place.

I. Ordinary prismatic compass, Fig. 4. Approximate cost, 5*l.* to 6*l.* Only suitable for rough traverses in flat country. Faults are inherent delicacy and inaccuracy.

II. Author's modified prismatic compass, Figs. 5 and 6, decidedly superior to old type, due mainly to the increased interval provided between the sight vanes, and the introduction of a rocking centre, allowing inclined

sights to be taken and inclination measured, and being provided with bubble levels. Approximate cost, 12*l.*

III. Miner's dial, rigid sights, Fig. 7, not recommended. Approximate cost, 6*l.*

IV. Miner's dial, rigid sights, Fig. 8. Approximate cost, 7*l.* 10*s.* to 9*l.* Suitable for work in flat country where readings to one degree are sufficiently accurate. For work in rough countries superior in durability to I. and II.

V. Miner's dial, rigid sights, with vernier reading to three minutes. Not recommended, as decidedly inferior to VI. and costing nearly same.

VI. Miner's Hedley rack dial, with vernier reading by sight to three minutes, rocking centre and side arc, with or without telescope, Figs. 9, 10 and 11. Strongly recommended as an excellent surveying instrument, with or without telescope, and for use by native surveyors superior to any other form. Approximate cost, 6 inches, plain sights, 15*l.*; telescope, 17*l.* 10*s.* The six-inch is the best size.

VII. Improved Hedley dials with interchangeable telescope and plain sights. Outside vernier, correspondence of readings of dial and vernier. Recommended, with suggested improvements, as a first-class surveying instrument, superior in many ways to the theodolite, and much more suitable for preliminary operations. Figs. 3, 12, 13, 14 and 15. Approximate cost, 5 inches or 6 inches, 21*l.* Its superiority over VI. is not *very* marked.

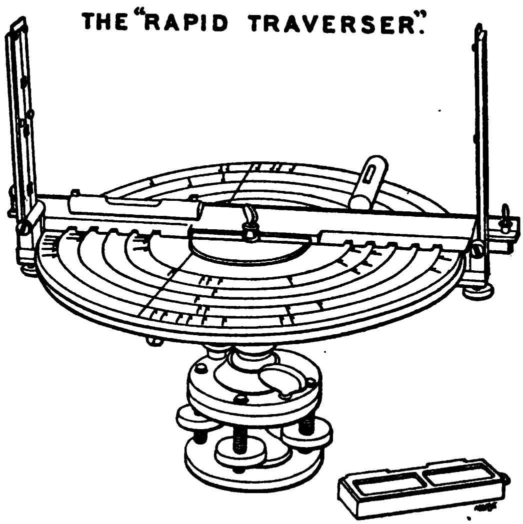
VIII. Mining theodolites, having outside verniers, reading to one or five minutes vertical arc. If one were

supplied with large anallatic lens telescope, it would make an excellent tacheometer, in some ways superior to the ordinary form. Certainly superior to the plain theodolite, but must give place to the transit for railway alignment work alone. Figs. 17 and 18. Approximate cost, 24*l.* to 28*l.*

A newly invented instrument, for taking angular measurements by direct means, as is done by the plane table, termed "Henderson's Rapid Traverser," is illustrated in Figs. 21 and 22, and the following description has been supplied by the makers, Messrs. John Davis and Son, of Derby, and Mr. J. Letcher, of Truro. This new instrument bids fair to supersede in some measure angle reading instruments, as it is very simple to work and its accuracy is incontestable. The principle is based on what is known as the plane-table system of surveying, and by its means, enclosed and open traverses can be accomplished, and subsequently laid down on paper with very great rapidity, facility and accuracy. The advantages claimed for Henderson's "rapid traverser" over the instruments now in use by surveyors and mine diallers are as follows:—

1. A very great saving of time, and this, in underground work at least, should be much appreciated.
2. Simplicity of construction.
3. Portability and non-liability to damage of any kind.
4. Great simplicity in working and in subsequently plotting the work. It, however, requires a most careful operator to work successfully.

The "rapid traverser" may briefly be described as a circular brass plane-table, having a brass "alidade" revolving round the same and being mounted on an ordinary dial stand or tripod. By means of the usual clamping screws, the circular table can be clamped to the stand and the alidade to the table. Upon the face of the table a disc of celluloid, Willesden waterproof



Figs. 21 and 22.

paper, or other suitable material, is fixed by pins constructed of any metal other than iron, the alidade being grooved so as to pass easily over the same. The disc of celluloid or paper is divided by concentric rings, while the fiducial edge of the alidade is notched out so as to afford to each annulus of the disc a certain length of fiducial edge, each length being distinguished by a number. The object of this is to allow of separate

surveys being accomplished by one disc, or to avoid overcrowding of direction lines in any one spot.

The "rapid traverser" is worked as follows. The instrument, both table and alidade being firmly clamped, is set on its tripod in the usual way and sighted (by a back-sight) on the starting point of the survey. The direction of the first line of the survey is then marked with a finely-pointed pencil on the selected annulus, and at the same time duly numbered or lettered in the space afforded by the notches in the alidade. The alidade is then unclamped and sighted to the forward line, and again clamped, and the direction and number or letter of the second line of the survey marked on the annulus as before. The traverser is then removed and fixed on the forward station, and adjusted so as to sight (by a back-sight) to the station it formerly occupied, and clamped. This done, the alidade is unclamped, sighted to another forward station, clamped again, and the direction or number or letter of the third line of the survey duly marked on the annulus, and so on for the remainder of the survey. In an enclosed traverse, if a peg or other mark be fixed at the end of the first line and the survey be so arranged, that this line shall also be the last line, then the directions of the first and last lines, as marked on the annulus of the disc, should exactly correspond, and a sure check as to the correctness of the work is immediately afforded. The magnetic meridian is taken at any convenient spot in the survey by means of a "trough" compass which is placed against the back edge of the alidade. The alidade and compass are then revolved together, until the needle

points to the north, when the line of the magnetic meridian is marked in on the disc. The lengths of the several lines, offsets, &c., are taken and entered in the surveyor's book in the usual manner.

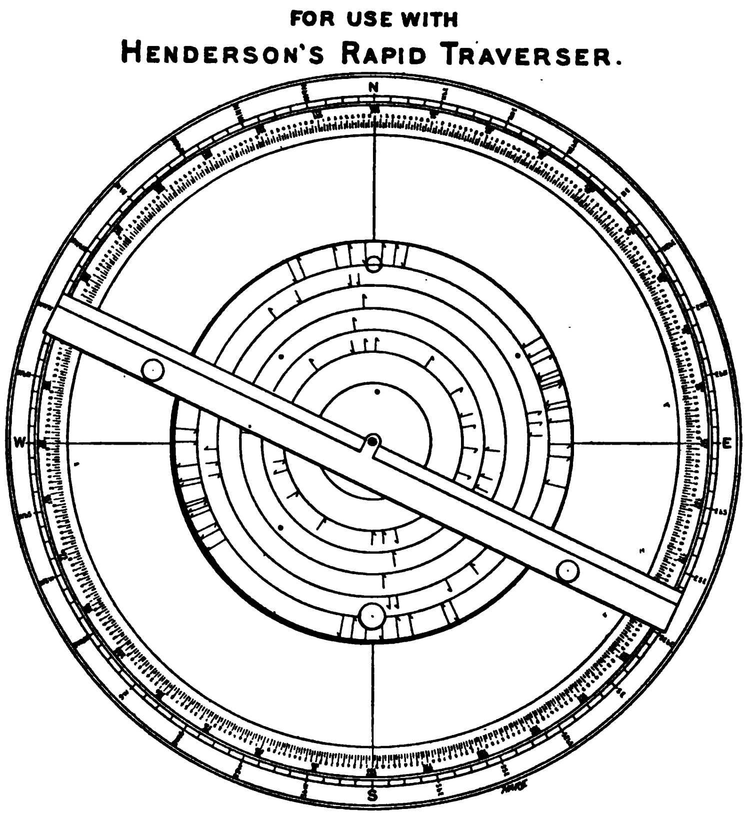


Fig. 23.

The sights of the alidade are graduated to give angles of depression or elevation up to 25 degrees, and thus the "rapid traverser" with plain sights can be used for all ordinary surface surveys, for the majority

of coal mines, and for the levels of metalliferous mines. For gradients of more than 25 degrees, or for more accurate reading of dips, a quadrant with sights, or with reversible telescope, is supplied. These accessories are quite unnecessary for above-ground land surveying, and the extra cost involved is considerable.

In plotting or laying down the work, the disc of celluloid is merely removed from its circular table, weighted down on the drawing paper, and the direction of the survey lines transferred in due order by means of the ordinary rolling parallel ruler.

For future reference the disc itself may be kept, the name and date of the survey being recorded thereon, or the magnetic tracings of the lines may be readily read off, and the same duly entered in the survey book. A convenient method of reading off the tracings, is to place the disc in the centre of an ordinary cardboard protractor (which has been cut for the purpose); the protractor is fastened down on a board, and the disc is pinned down in its proper position. A central metal spill projects from the board, and by means of an alidade constructed so as to work on this spill, the bearings are read off with ease and rapidity. *Vide* Fig. 23.

Mr. Henderson, M. Inst. C.E., the inventor, makes the following statement regarding the instrument which is quoted below :—

"The surprising accuracy of the 'rapid traverser' in a surface survey is a great feature in its favour, whether in the survey of a single field or of a large estate, and is especially applicable to town surveying,

and triangulating to distant and inaccessible objects. The simplicity of the instrument will be at once seen and recognised by the professional surveyor, who will find a source of pleasure in its use when he knows that it is registering truthfully the lines which he is running, however numerous or complicated they may be, with the very least degree of trouble to himself. To meet any objection that may arise that the plotting of the result of a survey or traverse made with this instrument is merely mechanical, and that no trigonometrical calculations can be made from it, it should be stated that all that has to be done is to remove the disc, place it in its proper position inside the cardboard protractor which ought to accompany the instrument, for office use only. when the tracing of every line on the disc can be taken, and entered in the field-book for future reference, as explained in the foregoing description."

Subjoined is a testimonial by Colonel G. H. Holland, late R.E. :—

"The great beauty of the design is that it is so simple, and that it eliminates three distinct sources of error in the ordinary method of traverse surveying.

"First. One may make a mistake in reading the angle of a theodolite.

"Secondly. One may make a mistake in entering the angle in one's surveying book.

"Thirdly. In plotting one's work from the surveying book one may again plot a wrong angle.

"All these errors are next door to impossible with the Rapid Traverser. The instrument deserves every praise. Few R.Es. have done so much traverse work

as I have, so, without vanity, I consider myself justified in giving a strong opinion."

The cost of the Traverser, as made by Messrs. Davis and Son, without quadrant or telescope, is 13*l*. 13*s*.

This instrument was originally designed for mining work, for which it is clearly not well suited. For above-ground work, on the other hand, it is undoubtedly a valuable acquisition. This design was brought out in 1894, but hitherto has not taken with the professional public. The reason is not far to seek. Considering the extreme simplicity of its construction, the price of the traverser is very excessive. It possesses no graduated arc, no vernier, no telescope, no attached level, hardly any permanent adjustments. In fact, a fair good workable copy could be made by any intelligent carpenter. Under these circumstances the Author considers that the price of the instrument should not exceed 8*l*. or 10*l*. at the outside, allowing for royalty. Were the price thus reduced to reasonable limits, there can be no doubt that this new instrument, which is certainly possessed of many very excellent qualities, would eventually come to be largely used by surveyors and also engineers.

CHAPTER II.

USE OF HORIZONTAL ANGULAR INSTRUMENTS IN THE FIELD.

THE chainage can be continuous, or close at each station as circumstances dictate. The field-book should have a line drawn across the page at each station, which should likewise be lettered A, B, &c., and the lines also, if necessary, numbered 1, 2, &c.

The fore-bearing of any line should be written above, the back-bearing below the station line, with arrow head to latter to punctuate the direction. Bearings from stations or intermediate points to objects to either side of the traverse line, should be noted on lines drawn in approximate direction.

WITH ORDINARY PRISMATIC COMPASS.

1. *Rapid Method.*—Setting up at alternate stations without check readings. Set up instrument at B, take back-bearing to A, note below line at B. Above line note bearing to C. Remove instrument to D, take bearing to C, fore-bearing to E, and so on.

2. *Check Reading Method.*—Instrument to be set up at every station, commencing with A. Fore-bearings entered above the station line, the back-bearings below.

The back-bearing is a check on the accuracy of the fore-bearing; if any small difference occurs, the mean of the two observations should be assumed as the correct one.

With Author's Modified Prismatic Dial (Figs. 5 and 6).

With these dials only fore-bearings should be read.

Rapid Method.—Alternate station readings. Set up at B. Set sights on line B A without reversing, and note fore-bearing A B above station line at A. Then take fore-bearing B C and note above line at B. Move instrument to D and note fore-bearing C D above line at C, and fore-bearing of D E above D, and so on.

Check Method.—As with prismatic compass, instrument to be set up at every station, but only fore-bearings read. The two readings at the end of each line should be identical; if not, the difference to be halved. The correctness of the adjustment of the sights is checked by double readings.

Dials with Rigid Sights.

Methods same as above.

Hedley Rack Dials (Figs. 9, 10, 11) and Improved Hedley (Figs. 12 to 15).

1*st Method.*—Setting up at alternate stations, angles taken being all north point meridian angles.

Set up at B. After levelling up, clamp collar of lower limb and set zero of vernier to that of graduated

circle. Then unclamp collar, loose needle, and set zero to the north point of the needle. Then clamp lower limb collar, and turn vernier and sights by the rack milled head in the direction B A, keeping the fore-sight towards B, and the back-sight towards A. The fore-bearing A B, should then be noted above line at A. If a telescope is used, it should be lifted out and reversed in its Y's. Next turn sights in direction B C, and to any other objects which may require to be taken. During these operations the needle naturally remains fixed at the zero point of graduated circle which remains rigid with the lower limb in the case of rack vernier dials, but corresponding in reading of vernier in the improved type. Next move to D, repeat operations exactly as before, taking fore-bearing C D by a back-sight and D E by a fore-sight, and so on. In these operations the vernier plate need not be clamped except on removal to prevent a strain on the instrument.

2nd Method.—Setting up at every station with check back observations. Same as above, except that double readings are taken at each station. This is repetition checking of each reading, which no other method affords. It is, however, slow and tedious.

3rd Method.—Vernier meridian angles taken, instrument not adjusted to north point except at first station. Set up at B, and proceed exactly as in 1st method. On moving to C, leave vernier plate clamped at fore-reading B C, and when set up at C unclamp lower limb collar and set sights in line C B by a back-sight. Then clamp collar, loose vernier plate, and proceed to take fore-bearing C D. The needle, if released, will point to zero

of the graduated circle, or to the same bearing as read by the vernier, as the dial is provided with inside or with outside vernier. This checks the operation and the adjustment of the sights. On removing to D, the vernier is left clamped and the lower limb again turned and clamped in direction C D, when vernier plate is unclamped for further observations. This operation can be continued at every station, the needle being only loosed occasionally as a check on the accuracy of the work. This saves the time always occupied in bringing the zero up to the needle and the vernier to the zero of the graduated circle involved in methods 1 and 2. It is, however, not so trustworthy as the last method, and takes longer than method 1. All the angles read are magnetic meridian angles.

4th Method.—By vernier angles. Set up at B. Procedure as in first instance. All angles taken from B are meridian angles, and the vernier angles taken subsequently, independent of the needle, can be reduced to meridian angles by means which will be hereafter noted. Remove to C. Bring up zero of vernier to that of dial, and clamp vernier plate, loose collar of lower limb, and turn the fore-sight or telescope to B. Clamp lower limb and loose vernier plate, and take angle B C D by turning fore-sight by the rack head to D. Then remove to D, and repeat operation. The needle is thrown up after being used at the first set up, and is not subsequently made use of. If the vernier angles are reduced to meridian angles, a check on the work can be made at any period of the traverse by clamping the vernier to this ascertained meridian angle

on the last fore-sight, when, if the needle is released, it should point to the zero of the graduated circle in the old form of dial, or to the same bearing in the improved Hedley. This method is identical with that ordinarily employed with the theodolite, and has the advantage of obviating the delays due to adjustment to the needle, but has the serious demerit that unless checked by the magnetic meridian, any error will be carried right through the traverse.

5th Method.—By keeping vernier plate and graduated circle clamped together with zeros corresponding and using the needle alone. The conditions then are identical with those of the Author's modified prismatic compass already alluded to, except that the bearings read are in some instruments inverted, and have to be reduced to true bearings by deducing each reading from 360°, or on paper can be plotted as they are by using a reverse protractor. This method is the best where the stations are numerous and close together, as in a traverse through jungle paths. For such purposes readings to half or a whole degree are quite sufficiently accurate. Where a long sight is obtained the vernier can at any time be brought into use.

CHAPTER III.

CLINOMETRICAL INSTRUMENTS.

In preliminary operations for mountain railways or for hill roads a clinometer is an indispensable instrument, as working with a level is a very slow and tedious process. These instruments can also be used for putting in contours starting from pegs on lines of cross section taken previously by the level.

A great variety of these instruments are made on different principles.

1. *Pendulum Clinometers.*—These are of various shapes and forms, but are all on the principle of the gravity of a heavy pendent body indicating the inclination of the sight line to the vertical. One of the simplest forms is that illustrated in Fig. 24, which represents Stanley's balance circle clinometer, price 25*s*.

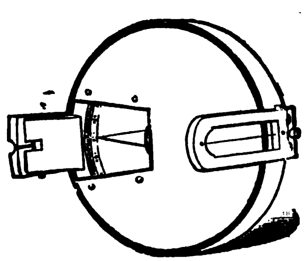


Fig. 24.

This instrument is in appearance like a prismatic compass. It is, however, held vertically as shown in illustration. The pendulum, which is hidden from view, is attached to a card graduated to half degrees from 0 to 360°, which is read by a prismatic reader

exactly as in a compass. The zero and 180° are marked by two triangular pointers on the card, and when either of these is read the line of sight is horizontal.

A similar instrument, but combining a hand dial, when held horizontally, is shown in Fig. 25, taken from Mr. Harling's catalogue.

In this the needle of the dial when in a vertical position acts as the pointer, becoming attached to a heavier pendulum. As a clinometer it does not desig-

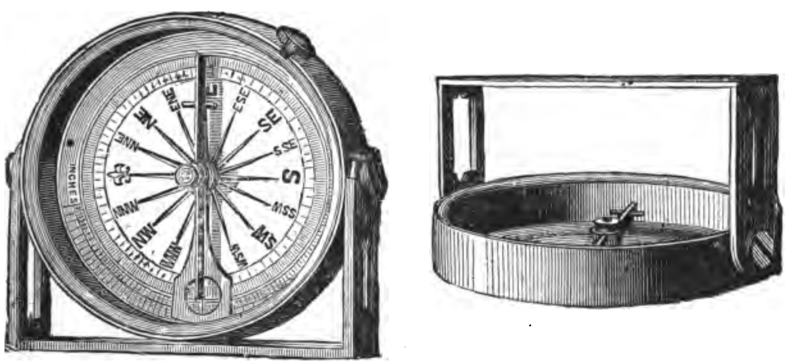


FIG. 25.

nate degrees of inclination, but inches in a yard, to be deducted for the proportion of hypothenuse to base.

Another form is termed Barker's patent combined prismatic compass and altitude instrument. The prism reads not only the degrees of inclination, same as in the compass card, but also the deduction in inches per yard. This is illustrated in Fig. 26, price 3*l.* 10*s.* to 4*l.* 4*s.*

Fig. 27 represents Hunter's combined altitude and prismatic compass, likewise taken from Harling's catalogue. In this the compass card and altitude disc are

distinct, the latter being drawn round to one side to clear the lower compass card. This instrument shuts up like a half-hunting watch, the line of sight for both kinds of observation being marked on the glass of the cover. Price 4*l.*

All these instruments, excepting Figs. 24 and 28, are mainly intended for mining or geological work, are hand instruments, and hence are not considered at all suitable for road tracing. They will indicate the in-

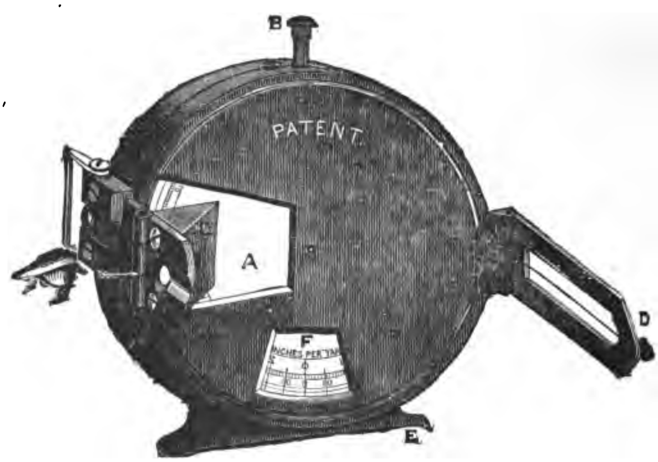


FIG. 26.

clination of the ground measured on the slope in surveying, and would hence be of utility where only the ordinary prismatic compass is employed.

A very superior instrument to any of these is Casella's pocket altazimuth, price 6*l.* 6*s.*, illustrated in Fig. 28.

This instrument is excellent for military or other reconnaissance work, being accurate and extremely portable. It is provided with attachment to a jointed

head mounted on a pole, whereby it can be turned from a horizontal to a vertical position as required. There

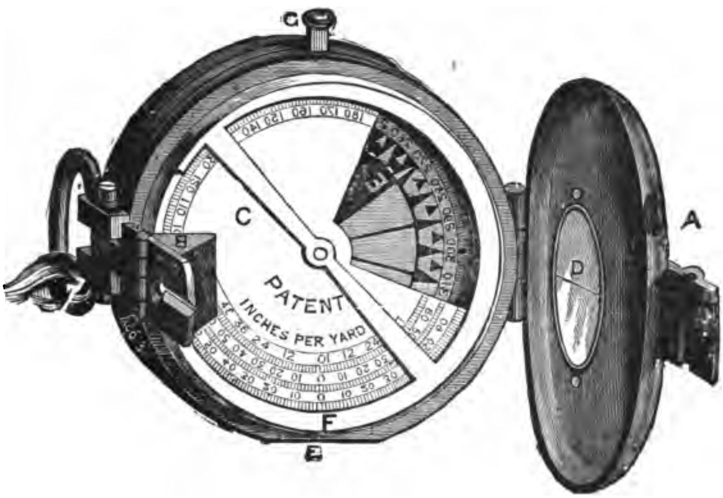


Fig. 27.

are separate graduated arcs on each side of the instrument, one being a dial with needle, the other the

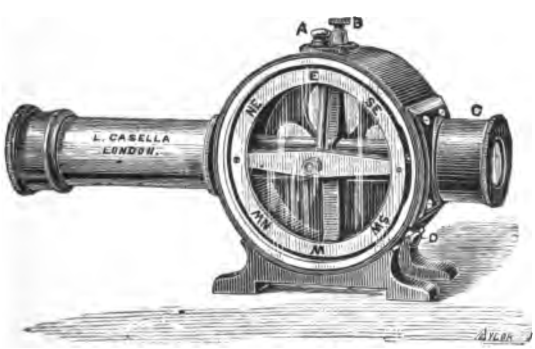


Fig. 28.

vertical arc. The vertical arc is of angle section, that is to say, it is provided with two tables at right angles

to each other, as in an angle iron. Both are similarly graduated. One is visible from outside; the other is seen distinctly through the telescope, when an observation is being taken. This ingenious arrangement places this instrument on a higher level than any other alt-azimuth, including the reflecting levels, which will be shortly described.

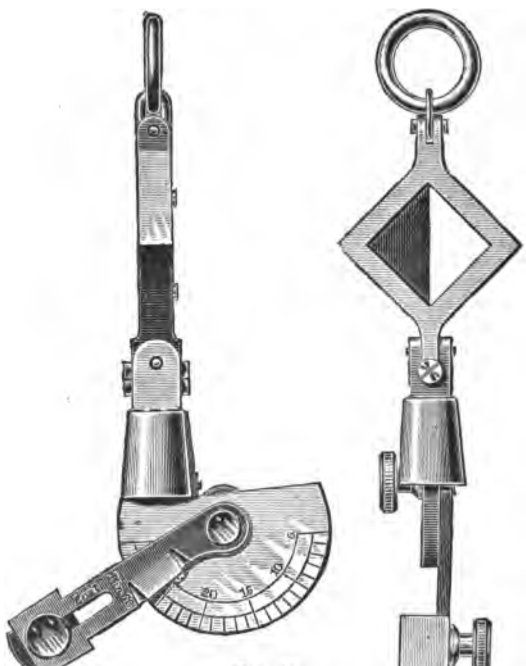


FIG. 29.

For road-tracing purposes, the Author is of opinion, that the class of instrument now about to be described, is decidedly preferable to all the foregoing.

First, the De Lisle clinometer, Fig. 29 — from T. Cooke and Sons' catalogue—is a remarkably simple hand instrument. The design is on the principle of

the reflection of images from a mirror. The sight hole consists of two halves of a square set on edge. One half is a mirror, the other open. The line of sight from the eye, looking at its reflection on an imaginary line drawn horizontally across the square, must be at right angles to the mirror, so that when the mirror is inclined, the line of sight is at right angles to this vertical inclination. Hence when the mirror is vertical, the line of sight is level; when inclined from the vertical, it is correspondingly deflected upwards or downwards. The instrument can be used for up or down inclinations, by simply turning the sight right round. The slopes required to be set out, from 1 in 8, to 1 in 50, are marked on a semicircular arc, and the swing balance adjusted to these marks, gives the required tilt to the mirror.

This instrument can be held in the hand to the level of the eye, or else hung on a hook projecting from a rod of such a height, that the distance of line of sight from the base of the rod, equals that of the T rod, the top of which is sighted.

Fig. 30 represents the Ceylon road tracer, manufactured and sold by Messrs. Walker Brothers, 36 Basinghall Street, E.C. This instrument consists of a brass tube hung from a pivot by two rods, with square sides, having a very small aperture at one end, and a larger square opening, with cross wires, at the other. Rigidly attached to the tube by two vertical bars, is a horizontal rod, up and down which a suspended weight can be moved. To the upper part of the weight is attached a pointer, by which graduations of road slopes from 1 in 5

to 1 in 120, made on the flat side of the sight tube, can be read.

The instrument, which is manufactured in Ceylon by native workmen, is crude and unfinished in the extreme. In spite of these manifest disadvantages, owing to the absence of any competitor of equally simple form, it has

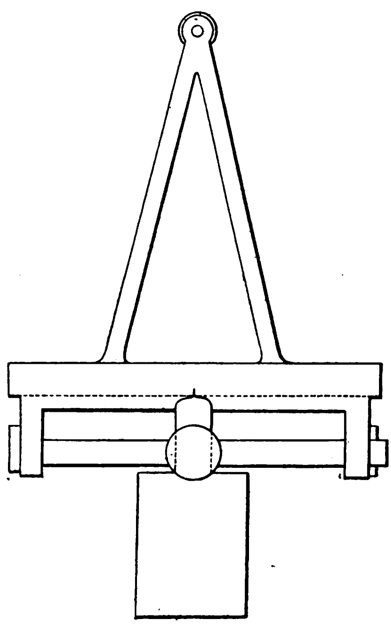


FIG. 30.

a large sale with planters all over the world, which its merits by no means justify. The instrument is fairly accurate; the sight tube, however, with its very small field of vision and absence of all lenses, is an absurdity, but has the *appearance* of accuracy, which imposes on non-professional persons. It is clear that a plain but accurate road tracer of low cost, somewhat on the

principle of a sliding weight, which could be worked by anyone, would be a decided desideratum. These the Author has endeavoured to provide by designing the instrument illustrated in Fig. 31, which is termed the " Planter's Road Tracer."

This instrument, Fig. 31, resembles in general form the Ceylon road tracer already described, but is a very decided advance on that crude design. It consists of a horizontal graduated bar or steel-yard, triangular in section, to the end of which two vertical plates are rigidly attached, which project above the bar, and are provided respectively with slit and hair horizontal sights, cut out of the plates. To the projections on top of these sight plates, two hollow inclined hanging rods are jointed, which are fastened at their other ends by a simple connection to the pivot joint on which the balance swings, thus forming a triangle with the bar. Above this pivot is another joint, allowing lateral motion, and this again passes through the top bar of the frame, forming a swivel. The instrument can thus be turned in any direction, and from the second joint swings always to a vertical position, thus insuring the sights being horizontal.

On the triangular graduated bar, are attached two weights, which have free motion up and down the bar, and can be secured in any desired position by a clamp screw. These weights are enclosed between the vertical sight bars at the extremities of the steel-yard. When the weights lie at the extremities of the graduated bar, the latter, with the line of sight which is parallel to it lies truly horizontal. In order to incline the line of

sight to any of the slopes marked on the bar, if the direction be upward, the weight furthest from the observer, who stands opposite the slit-sight, should be

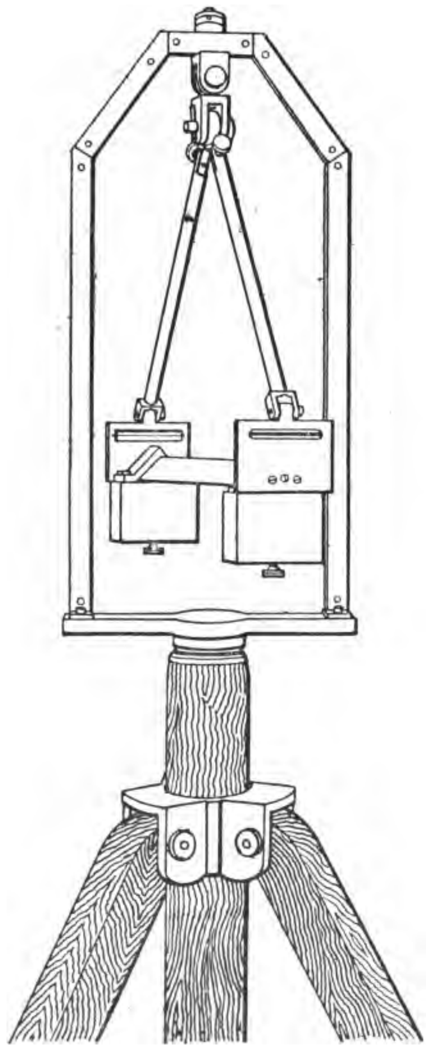


FIG. 31.—PLANTER'S ROAD TRACER.

pulled back along the bar, till its inner bevelled side corresponds with the required mark on the sloping side of the triangular graduated bar, and then clamped. If a downward slope is required, the other weight is similarly shifted forward. Each side of the bar is separately graduated for either weight. Thus it will be seen, that one weight only is moved, the other remaining clamped at one end of the bar. The advantage of this arrangement over the ordinarily employed single central weight is, that the distance travelled by one of the double weights, is twice that which would be covered by the single central weight, to produce the same result, and consequently the graduations are more distinct and the instrument has far greater delicacy and precision. When aligning a slope, the instrument should first be swung pendulum-wise in the direction of its length, and on the stoppage of the swing, the sight to the T staff held by the staff-holder can be taken. The frame, which is of hollow brass square tubing, is screwed on to a wooden post.

The distance from base of post to line of sight, being that of the T staff—in this case 4 feet 6 inches—the instrument can be used as the Ceylon tracer, by holding the post as nearly vertical as possible, with one hand. As this procedure is, however, inconvenient and productive of error, the post, when adjusted vertical, can be held in position by a tripod (*vide* illustration), through a socket in the head of which the post passes. This tripod does not carry any weight, its functions being limited to holding up the instrument. The post is round and fits loosely in the socket of the tripod, which can be pitched at any

height provided it is clear of the base of the frame. The post is leaded at base and provided with a short spike. The pivot, which is a smooth steel pin, should be kept well lubricated and perfectly clean, as otherwise error will result. The plain pivot joint works well and freely, but antifriction bearings would be a decided improvement, which will be added in future. The graduations are made by experiment, using a level and staff. The price of the instrument, with antifriction centred pivot joint, is *7l. 7s.* This invention is protected by provisional patent.

The next type are termed reflecting levels. These are small light telescopes held by hand to the eye, and so constructed, that an outside spirit level is reflected in the telescope, and can be seen simultaneously with the object.

The simplest form is Locke's pocket reflecting level, shown in Fig. 32, taken from Mr. Harling's catalogue.

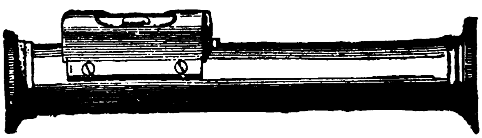


FIG. 32.

This, however, merely gives a level line of sight, and is used mainly for contours. The operator stands over a peg in the ground whose reduced level is known, and directs a staffman furnished with T rod of same height as observer's eye, up or down hill, till the top of the rod corresponds with the line of sight. Price, 12*s.* to 16*s.*

A reflecting clinometer level, which has a semicircular arc graduated, partly in slopes from 1 to 1 to 1 in 20, and partly in degrees, is illustrated in Fig. 33, and is termed Troughton's level, and with Fig. 34 is from Troughton and Simms' catalogue. The price is 1*l.* 5*s.*

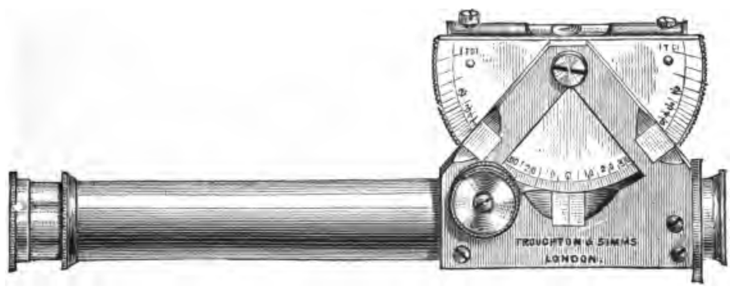


FIG. 33.

Fig. 34 represents Abney's level. Price 2*l.* In this the pointer is provided with a vernier to read the degree graduations in the arc, while the outer edge of the

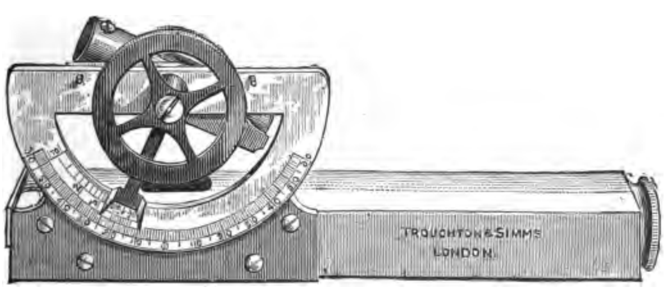


FIG. 34.

vernier plate reads the proportion of slopes of ground, which are marked at the inner rim of the semicircle.

In these instruments the outside level is kept horizontal by the reflection of the bubble being seen within the telescope.

Fig. 35 represents the Abney-Troughton clinometer, superior to either of the above, being provided with rack movement, which Abney's has not. It is, however, three times as expensive. Price 6*l.* It is from Stanley's catalogue.

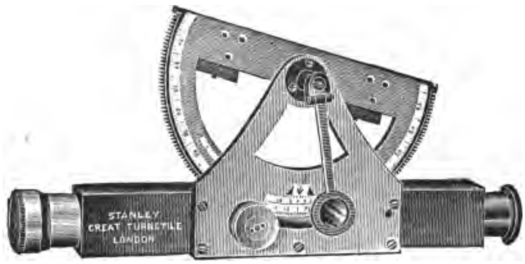


FIG. 35.

Fig. 36 represents Abney's level combined with a prismatic compass, by Negretti and Zambra. The cost is 3*l.* This is an excellent hand instrument for military topographical purposes or any mapping on a small scale.

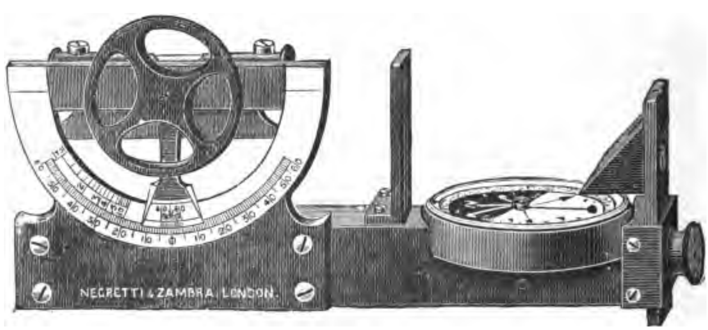


FIG. 36.

In the Author's opinion reflecting levels of any kind are more suitable for military reconnaissance work than for the operations of the civil engineer, and this applies to all instruments not mounted on a tripod. The De

Lisle and Ceylon road tracers are both superior to all of this type for road-tracing purposes, in spite of their racks and verniers, as the former are generally used hung on a staff of fixed height above the ground. The height of the eye varies with each operator, and also in the same person with the thickness of his boots, and the way he poses his person and places his feet. The reflecting levels could undoubtedly be pivoted on a tripod; they are not so made, but have flat under-surfaces, to

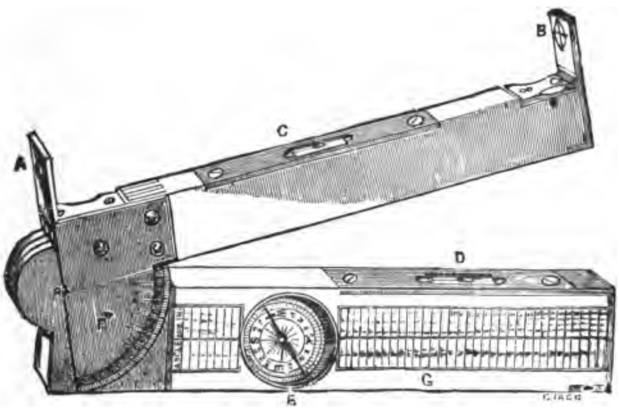


FIG. 37.

lie on a table, and it is presumed are levelled up by such primitive appliances as placing straws underneath.

The next type is the common boxwood hinged clinometer with spirit level, and its developments. This instrument cannot be used as held by hand to the eye, but must rest on a tripod. The common variety is illustrated in Fig. 37.

This instrument is really only suitable as a drain

clinometer used with a stretched cord, and unless mounted on a tripod is useless for engineering purposes.

Davis's new clinometer, illustrated in Fig. 38, is an immense improvement on this old type, though similar in form. It is made of metal, and is mounted on ball-

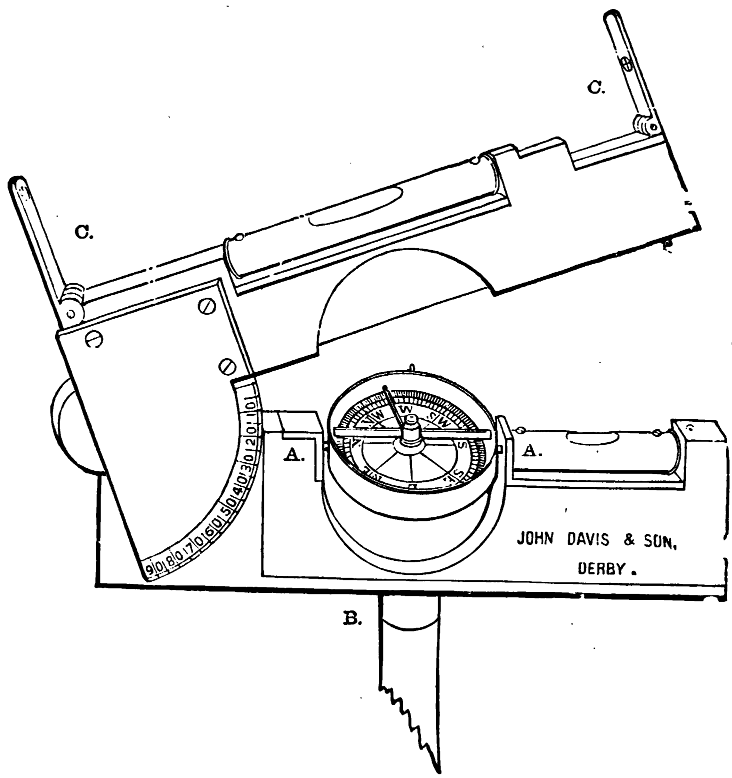


FIG. 38.

and-socket joint on tripod. This latter is very short, being intended for use in mines. When ordering, the ordinary long tripod as with prismatic compass, should be specified. Like all Davis's instruments, unless specially ordered to be bronzed, it is supplied in bright

brass, which is objectionable for above-ground work. The Author considers this instrument, for its size, decidedly good for road-tracing purposes. It is, however, believed to be capable of considerable improvement, for this special work, as will be pointed out later. The price is 4*l.* 4*s.*

The following description is quoted from the makers' catalogue. "The clinometer as shown is capable of doing the work of a Hedley dial or level approximately, although it is not intended to take the place of either. Where great accuracy is not required, it will save time and a more expensive instrument, and may be used where a level or dial cannot, on account of its extreme portability. It is 6½ inches long, ½ inch wide, and 3 inches deep."

The quadrant arc is marked in single degrees. The compass is graduated reverse, as it should be.

Louis' improved Davis's clinometer is no improvement for road-tracing work, being only suitable for mine surveying, and so will not be illustrated or described.

The Author's combined prismatic dial and clinometer, illustrated in Fig. 5, is adapted for use as a clinometer, as indeed can all dials be. The side arc is naturally much larger than in the last example, and by means of a vernier pointer, vertical angles can be read to five minutes. The prismatic dial, being adjustable vertically, is eminently suited for road tracing. It has already been fully described on pages 9 and 12.

Figs. 39 and 40 illustrate Negretti and Zambra's improved telescopic prismatic compass and clinometer. Cost 12*l.* 12*s.* This instrument is on a different prin-

ciple to any of the foregoing, and is a cross between the pendulum and the spirit bubble varieties. It is carried on a tripod and fitted with turnover ball-and-socket joint, and consequently is of decided practical use.

The one great drawback to all clinometrical instruments mounted on tripods, including the theodolite, is the unavoidable variability in the height of the instrument.

Fig. 39.

Fig. 40.

ment. Consequently adjustable vanes have to be employed on a level staff, or a T staff of adjustable length has to be used, and this necessitates frequent communication between the staffmen and the operator, involving great and vexatious delay, besides a liability to error.

The Author has designed a clinometer, Figs. 41 and 42, built by Mr. W. H. Harling, on the principle of adjusting the height of line of sight to that of the fixed

staff. This cannot be done by pitching the tripod, so that it is effected by the instrument being mounted on a vertical rod, which slides through a boss cast on head of

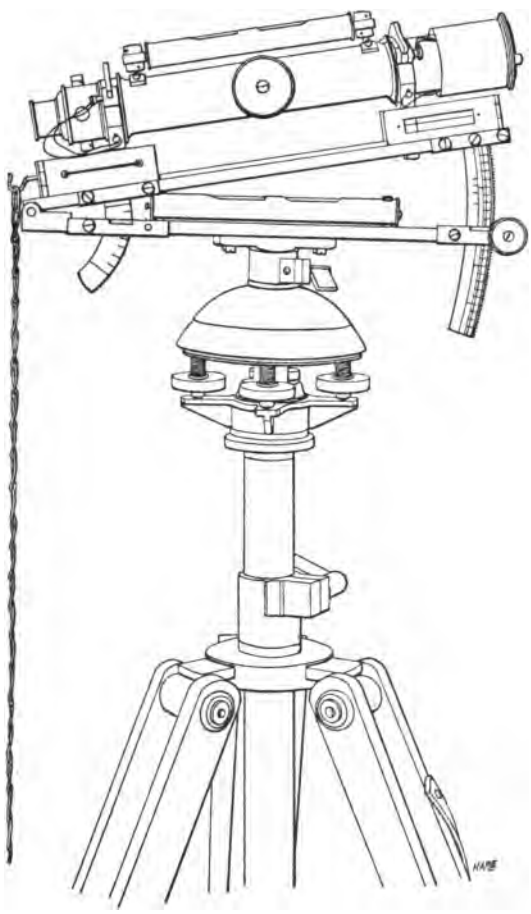


FIG. 41.

tripod, up and down between the tripod legs. A Hoffmann, or ball-and-socket levelling head, is fixed to the top of the rod, and in its turn carries the instrument.

The socket is provided with a powerful clamp. This is a similar arrangement to that already described as adopted

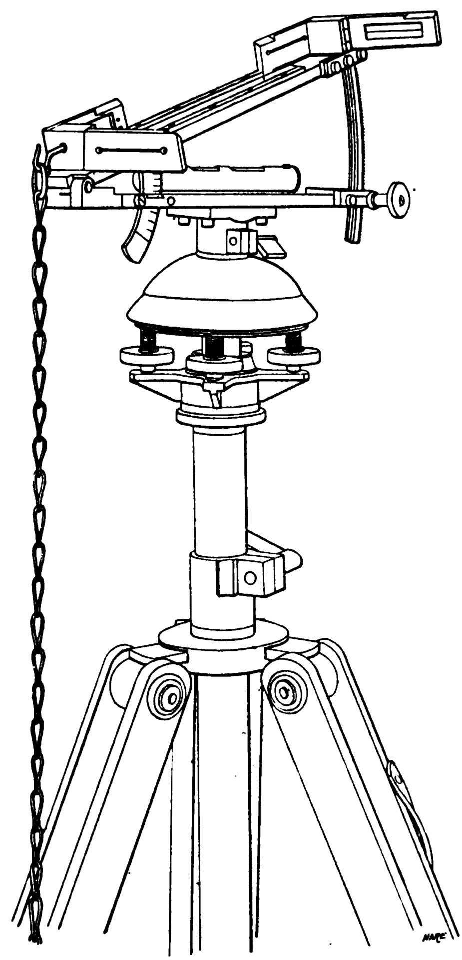


FIG. 42.

in the combined prismatic compass and clinometer, illustrated in Fig. 5, pages 9 to 12.

To adjust the height of line of sight above ground

peg, which should exactly equal that of the T staff, a drop measure chain is attached to the back hinge of the clinometer, of the requisite fixed length, carrying a metal disc at its extremity. The operator moves the instrument through the socket up or down, till the disc just touches the top of the peg. The construction of the instrument itself has some special points which might be noticed. Its general structure is similar to the clinometer, illustrated in Fig. 39. The lower limb consists of a mere narrow plate one inch wide, ten inches long, in the centre of which a five-inch level is mounted. This level protrudes through the upper plate, which is hinged to the lower, a rectangle being cut out for the purpose. When used as a level with plain sights, the upper plate is shut down flat, the spirit-level acting for both. The upper plate when down, is secured tight by a clamp screw. The exact parallelism of the two plates, which is a matter for the manufacturer to adjust, can easily be tested by applying a spirit-level. A separate level for the upper plate is clearly superfluous. It is unnecessary in the Davis clinometer for above-ground purposes, but that instrument was specially designed for mining work, where the conditions are different. The sights consist of two pairs, alternate slit and hair, so that a separate pair are used for uphill, and downhill alignments. These are fastened by hinges on each side to a dwarf standard, which is screwed at the ends of the upper plate. The sights, when not in use, fold inwards, and abut on a projection in the upper plate, and also fit against the side of the telescope standards, when these latter are mounted. There are two graduated

arcs, one at the extremity of the jaws, and one near the hinge. These are supplementary to each other. The fore-arc has a very large radius, about 9½ inches, and is graduated to ¼ degrees on one circumference, and on the other to a number of road or railway gradients from 1 in 100 to 1 in 8. The back-arc takes up coarser inclinations of 1 in 1, 1 in 2 to 1 in 5, and comes into play, when the fore-arc is lifted out of gear. The latter has a rack cut on one side, and is actuated by a pinion attached to lower limb. The former has merely a clamp, which should never be left on the instrument, but only brought into use when required. This is necessary to avoid straining the upper limb in case the clamp is left on, the former being of very light section in the centre.

Fig. 42 represents the instrument, with two of the wing sights out. Fig. 41 is the same instrument with the plain sights all folded in, and the telescope fixed. The latter is a ten-inch level telescope, with a long bubble. The instrument is complete without the telescope, which can be fixed or not, as required. The telescope is mainly for use for contour levels, when very long shots can be taken. No dial is provided, as from the Author's experience the two operations of road tracing or contouring, and surveying cannot, as a rule, be profitably carried out simultaneously, but if so required, Fig. 5 can be used.

The new clinometer level, just described, is carried on telescopic legs of the camera pattern. The object in this is, that when the instrument, as is commonly the case, is set up on steep sidelong ground, one or two of

the legs can be shortened at will. This instrument is further designed for use as a rough or contouring level. The advantage it possesses over the ordinary level is, that besides being sufficiently accurate for such purpose, contours can be taken very rapidly, as no staff is read, which immensely simplifies the work, and is particularly applicable to native subordinates, who do the bulk of surveying in India. For taking cross sections of uneven ground, or on a hill-side, the instrument is very rapid in work. In such cases, it is set to any convenient slope, and a level staff read off, as in the case with theodolite levelling. For these cross sections, a roughly marked staff in decimals of a foot, is amply good enough when the plain horizontal sights can be used. The results are easily sketched in the book and plotted afterwards, the height of sight line above peg, being a constant quantity. For combined accuracy and rapidity of work, in the particular line for which it is designed, this instrument is believed to stand absolutely unrivalled. It should be noted that when the telescope is used, the drop measure chain is capable of being shortened by a fixed mark, which ensures uniformity in height with the T staff. The price of this instrument is, without telescope, 11*l*. 10*s*.; with ditto, 14*l*.

The Author has found by experience, that manufacturers in a large way of business are by no means keen in taking up the building of newly designed instruments, particularly by unknown persons. The innate conservatism, so prominent a feature in English manufacturers generally, and which is the cause of much loss of trade, which Americans and foreigners consequently snap up,

is as marked in the case of some scientific instrument makers, as in other branches of trade. In the present case, the cost of making the three experimental instruments was defrayed entirely by the inventor, and in spite of this, one firm declined to trouble about the new work, unless a guarantee was given, that a certain number of the instruments would be ordered. The inventor, who had no means of ensuring this, applied to Mr. Harling, who made no such stipulation, and was exceedingly obliging in this troublesome matter.

CHAPTER IV.

METHODS OF PLOTTING WORK.

THE simplest method of plotting is by a circular protractor. This is laid on a convenient spot with its zero and 180° on a north meridian line drawn on the paper. Plain protractors are of various sizes from six inches upwards. The brass is the best, then white celluloid, vulcanite and paper. Paper protractors are used of

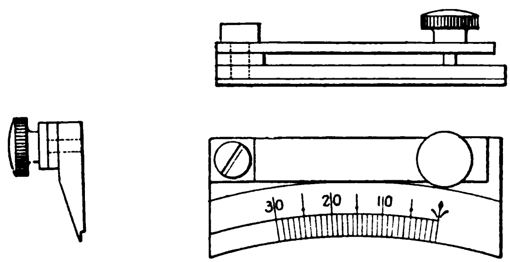


FIG. 43.

large size, 12 to 18 inches in diameter, and give very accurate results. For plotting minutes, a vernier has to be used. The simplest form is illustrated in Fig. 43, and consists of a loose brass graduated plate which revolves round the edge of the protractor. The latter should be provided with projecting pins, so as to slightly raise the edge, to allow of the under lip of the vernier plate passing

underneath. These verniers can be made to suit any diameter of protractor, and can be used with celluloid or even paper protractors, and for reverse plotting can be graduated in reverse way. The vernier is of the reverse, or (N + 1) description, so as to clear the fore part of protractor. After the vernier plate is properly adjusted to the protractor, the point is marked by pressing an attached spring pin. A much more precise variety of vernier protractor has one or two arms (folding in the case of two), on which a line can be drawn, radial to the centre point of the protractor. These vernier protractors are expensive, costing: single arm about 2*l.* 5*s.*, double folding, 5*l.*

Another system of plotting is by means of chords. A circle is drawn of radius to some multiple of 10 to the scale used. Across this the N.S. and E.W. lines are drawn. The meridian angles noted in the book have then to be altered to reduced bearings, i.e. are divided into the four quadrants of the circle, N.E., S.E., S.W., N.W. This is effected as follows. Any bearing under 90° is placed in the N.E. quadrant without alteration. From 90° to 180° subtract from 180° and place in S.W. quadrant. From 180° to 270° deduct 180° and place in S.E. quadrant; and 270° to 360° subtract from 360° and place in N.W. quadrant.

The angles thus reduced, are the angular distance right or left from the north and south points. The chords corresponding to the angles, are obtained from a table of chords, one of which is given in Appendix; the figure should be multiplied by 10 if the radius is 10 chains, or 1000 feet, or 20 if same is 20 chains, and so on. The

product, being chains and links, or feet and decimals, as the case may be, is then set off with a compass from the N. or S. points in the quadrant to which the angle belongs, cutting the circle at a certain point. The line joining the centre of the circle, and this point on its circumference, gives the required inclination, which can be run off to the traverse by a parallel ruler.

EXAMPLE.

Meridian Angle.	Reduced Bearing.	Chords, Radius 1000.	Distance.
297·30	62·30 N.W.	1037·5	
21·15	21·15 N.E.	347·2	
319·00	41·00 N.W.	700·4	
261·30	81·30 S.W.	1305·5	

In case a table of chords is not available, the calculation can be made by using natural sines, or logarithms, or by means of the slide rule. The formula for length of chord is $C = 2 \sin \frac{\theta}{2}$, where θ is the reduced bearing, or angle of divergence from the north meridian line in its several quadrants.

When meridian angles are not taken, except on the first line, as is commonly the case with theodolite surveying, the vernier angles noted have to be reduced to meridian angles, so that all can be pricked off at one time on a protractor. This is much more convenient, than putting the protractor on each line of the traverse successively. The meridian need not necessarily

be the north meridian ; the direction of the first line of the traverse can be assumed as meridian. The rule for reducing vernier angles to a common meridian, is as follows :

To the first meridian angle add the next observed horizontal angle. If the sum exceeds 180° deduct that amount from it ; if less, add 180°. If after the deduction of 180° the remainder then exceeds 360°, deduct that amount as well. This gives the second meridian angle. Repeat this process for the third, and so on.

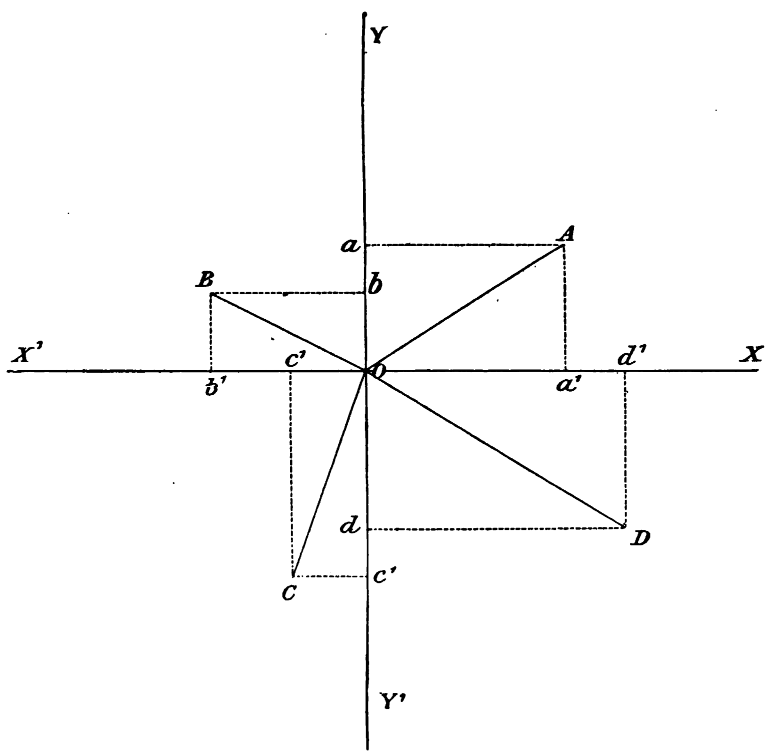
The following example will explain the procedure, and is taken from Bennett Brough's treatise on 'Mine Surveying':—

Meridian 0°·00 + 1st angle 121°·27 . = 121°·27′, No. 1 M angle
No. 1 M. angle 121°·27′ + 2nd angle
97°·36′ = 219°·03′. Deduct 180°.

219°·03′ − 180° . .	. =	39°·03′,	No. 2	„
(39°·03′ + 209°·01′) − 180°	. =	68°·04′,	No. 3	„
(68°·04′ + 159°·40′) − 180°	. =	47°·44′,	No. 4	„
(47°·44′ + 195°·32′) − 180°	. =	63°·16′,	No. 5	„
(63°·16′ + 85°·31′) + 180°	. =	328°·47′,	No. 6	„
(328°·47′ + 152°·07′) − 180°	. =	300°·54′,	No. 7	„
(300°·54′ + 103°·34′) − 180°	. =	224°·28′,	No. 8	„
(224°·28′ + 104°·03′) − 180°	. =	148°·31′,	No. 9	„
(148°·31′ + 262°·58′) − 180°	. =	231°·29′,	No. 10	„
(231°·29′ + 69°·58′) − 180°	. =	121°·27′,	proof.	

In the chord system of plotting already described these meridian angles will have to be further changed into reduced bearings. The same procedure has to be adopted in case the work is plotted by rectangular coordinates. This last is the most accurate method of any. It consists in assuming two axes O X and O Y crossing at right angles to each other at fixed point or origin O,

and in calculating the perpendicular distances or co-ordinates of each station from those axes. As in diagram, the positions of A, B, C, D in the four quadrants are deduced



by setting off the co-ordinates a A, a' A and so on. This fixes the point A. The line O A represents the direction and length of the traverse line.

The angle A O Y is the reduced bearing N.E.

A a is termed the latitude = O A cos bearing.

A a' ,, ,, departure = O A sin ,,

The inclined distance O A is known, having been measured during the traverse.

The calculation of the co-ordinates being a very tedious process, traverse tables should be used, a set of which are given in the Appendix. Co-ordinate protractors, which obviate any calculations, are also used, one of which is illustrated in the treatise on Mine Surveying, Fig. 4.

In plotting, the line Y is taken as the north and south, X as west and east. Northings and eastings plus, southings and westings minus.

The following example will explain sufficiently. It is also borrowed from Mr. Bennett Brough's valuable work :—

Line.	Angle.	Bearing.	Reduced Bearing.	Distance.	Latitude.		Departure.	
					N.	S.	E.	W.
				links.	links.			
O A	0·00	32·15	32·15 N.E.	176	148·85		93·91	
A B	220·17	72·32	72·32 N.E.	180	54·02		171·70	
B C	79·13	331·45	28·15 N.W.	155	136·54		..	73·36
		Total			339·41		265·61	73·36

"Before these calculated co-ordinates can be used for plotting purposes the total latitudes and total departures must be calculated for each point. This is done by taking the algebraical sum at each station as follows :—

Station.	Total Latitudes from Station O.	Total Departures from station O.
	links.	links.
O	0·00	0·00
A	+ 148·85	+ 93·91
B	+ 202·85	+ 265·61
C	+ 339·41	+ 192·25

"Having prepared this table, draw a meridian line through the first station O, along the meridian. North latitudes are set off upwards, south downwards. East departures are set off perpendicularly to the right, and west departures perpendicularly to the left. In this case set off along the meridian in a northerly direction, the latitude 148·85 links to the scale adopted. This gives the point *a*. From that point set off perpendicularly to the right, the departure 93·91 links. The station A is thus fixed in the plan. Join O A. This should measure the distance 176 links given in the table. Similarly for the next point B. From O again set off upwards 202·87 links to *b*, and from that point 265·61 links perpendicularly to the right. This gives the point B. Join A B, which should measure 180 links, and so on. In a closed traverse the sum of the north plus latitudes should equal that of the south minus latitudes, and that of the east departures that of the west. If there should be a slight error, the latitudes and departures must be corrected so that their sums shall be equal in each case." *

* The figure referred to is not identical with that on page 75.

This is done by distributing the error among the lines in proportion to their length, the balancing being effected by the following proportion. As the sum of all the lengths is to each particular length, so is the total error in latitude or departure to the correction of the corresponding latitude or departure. It may frequently be made by determining the error by chain, without making the exact proportion.

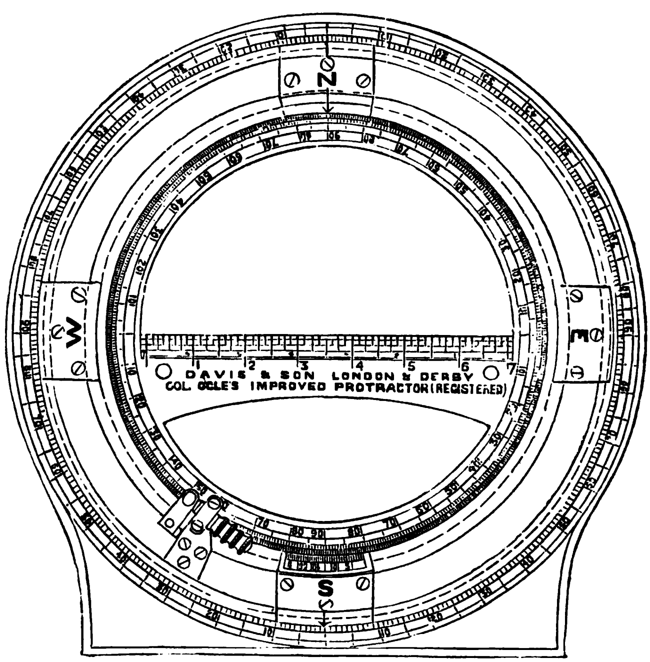


FIG. 43A

Fig. 43A illustrates a protractor termed Ogle's Improved Protractor. This instrument has been designed to facilitate the more accurate and speedy plotting of surveys. It consists of three parts :—

1. The outer frame with a true edge working in a T-square.

2. The intermediate ring to rotate in this frame.

3. The inner ring or protractor proper, which is also free to rotate within the intermediate ring.

The Ogle protractor obviates the necessity for the use of the parallel rule. The cross bar is divided as a universal scale, thus combining the protractor, parallel rule and scale. When using the Ogle protractor the N. and S. points on the intermediate ring are placed parallel with the meridian line of plan, clamped in position, and so remain fixed at the correct angle to the T-square until the completion of the plan. The inner ring or protractor is rotated until the particular reading in regard to the N. and S. points on the intermediate ring is obtained, and the line of the correct length is drawn by means of the scale on the cross bar. The price of this instrument is 7*l.* 10*s.*; with vernier and tangent screw as illustration, 9*l.* It is made and sold by J. Davis and Son, Derby.

CHAPTER V.

LEVELLING INSTRUMENTS.

THE ordinary level, dumpy or Y, will probably always continue in demand, although new inventions tending to simplification of work will in time oust them to a great degree from universal usage. The dumpy or Gravatt's level is essentially English, as it is not appreciated anywhere else. American engineers have apparently a distrust of instrument makers, and have always retained the use of the original form of level, the Y. In England the Gravatt level has reigned supreme for many years, but signs are not wanting that, in company with the plain theodolite, it is eventually doomed to extinction. Y levels, much improved in construction from the old type, and modifications of the dumpy, are slowly but surely elbowing the former out. English engineers are exceedingly conservative in professional matters, and do not willingly abandon instruments they have been accustomed to use, for any new-fangled devices however plausible. This want of adaptability cannot be characterised otherwise, than as unreasonable.

The dumpy level has the advantage of having the telescope rigidly fixed to the base plate, that is, at right angles to the vertical axis, so that one adjustment

necessary in the Y variety is not required at all. On the other hand, the adjustment for collimation is decidedly awkward and troublesome to effect. In England levels are generally sent to the instrument maker for adjustment; this cannot be done abroad, and hence there is a strong feeling in favour of those that can be tested and adjusted by the engineer himself. This has

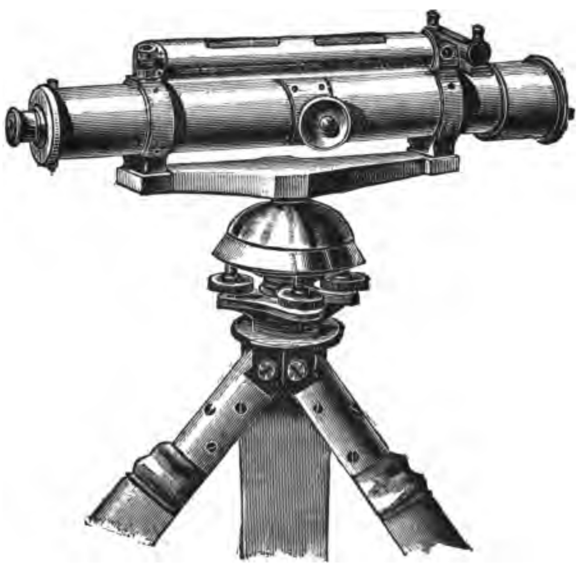


FIG. 44.

led to the adoption of Cooke's and Cushing's patent reversible levels, and the Troughton and Simms' Charlton model Y, and Stanley's Y, which claim to unite the advantages of the solidity of construction of the dumpy with the adjustability of the Y.

Fig. 44 represents a dumpy by Davis, with the object of showing the Hoffmann levelling joint with which it is provided, undoubtedly the best form, as

being easier and quicker to work than the tribrach, and infinitely more so than the time-honoured four-screw. This superiority is particularly noticeable when setting up on uneven ground.

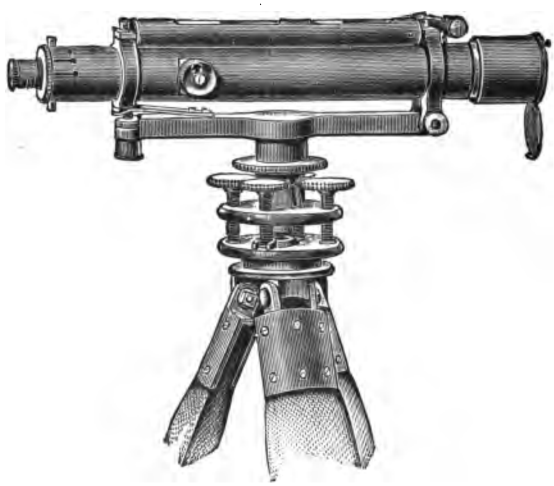


FIG. 45.

Fig. 45 shows Troughton and Simms' form. In this the parallelism of the telescope to lower plate is adjustable, but the level is fixed rigidly to the former. It can be supplied with the tribrach stand if required.

It is a remarkable but indisputable fact, that the old system of parallel plates and four-screws is still tenaciously held to by some surveyors.

Stanley's new model level, a dumpy of excellent construction, fitted with prismatic compass on lower limb, is illustrated in Fig. 46.

In the Author's opinion, a compass is an unnecessary adjunct to a level, as the double operation of levelling and traversing, cannot be conveniently or profitably

carried out simultaneously. The former requires the undivided attention of the operator, and the level forms a clumsy and heavy mount for so small a traversing instrument, as a dial or prismatic compass. It is better that the traverse precede, or follow the levelling as an independent operation.

Fig. 46.

The cost of dumpy levels varies with different makers, but may be set down as—with compass, 1*l.* per inch; without, 1*l.* off.

Y Levels.

This class of level has been much improved of late years, and with the reversible level, to be described later on, are believed to be sure eventually to displace the dumpy for colonial work. Y levels are somewhat more expensive than dumpies.

Messrs. Troughton and Simms in their Y levels place the spirit-level on the lower limb, not on the telescope. This arrangement the Author thinks is a good one. Fig. 47 represents this firm's Y level, the example being a 12-inch.

Fig. 48 represents the Charlton model level. This last possesses many valuable points, which are enumerated below from a description supplied by the maker. Price, 14-inch, 13*l.*

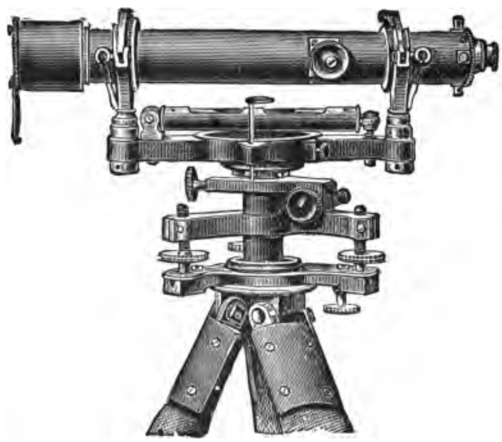


FIG. 47.

"The instrument consists of a stage *a* carrying a bubble *b* whose surface may be made truly horizontal by means of the bubble *b*.

"The bubble *b* is adjusted to maintain its central position upon rotation of the axis by means of the nuts *d*, which move it relatively to the lower stage *c*.

"The telescope *e* is furnished with cylindrical collars equal to each other in diameter; it can be rotated in its bearings *h* and can be turned end for end in these bearings, as in an ordinary Y level. The bearings *h* are constructed so that when the telescope is collimated, the optical axis shall be parallel to the stage, therefore (when the bubble is in the centre of its run) level. When adjusted, the screws *i* which hold the collars in

the bearings are tightened; the telescope thus becomes united to its supports, and the stability of Troughton's level is obtained without losing the advantage of the ease attached to the adjustment of the Y level.

"To adjust for collimation, release one of the capstan-headed screws on each bearing, then setting the telescope on a mark, bisect it with the horizontal wire; now rotate the telescope in the supports, and if the mark be not bisected, move the wire half the distance by the collimation, and the remaining half by the parallel plate or tripod screws. The telescope is collimated when, upon rotation in its bearings, the horizontal

Fig. 48.

wire cuts the mark. Now tighten the collars and adjust for reversion by the nut *d*.

"The bubble *b* is not to be touched as it is supposed to be fixed in position by the maker of the instrument."

The following instruments for rougher work are illustrated below.

Fig. 49 is Stanley's builder's level. Price 3*l.* Remarkable for its low price. A cheap type of this

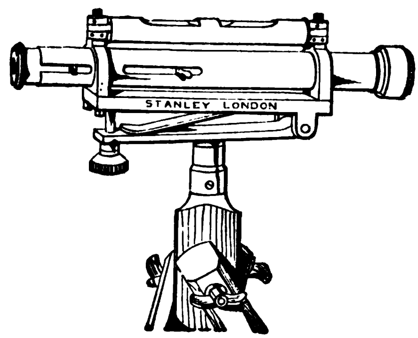


FIG. 49.

description is quite good enough for levelling operations connected with a building, bridge, or lock.

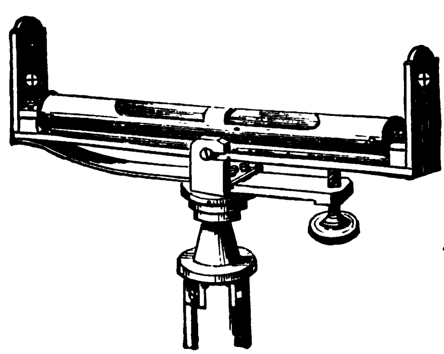


FIG. 50.

Fig. 50 represents Negretti and Zambra's Ordnance pattern drainage level. Price 5*l.* 5*s.* An excellent little instrument for close work not requiring a telescope.

We now come to a class of level of comparatively

recent introduction which combine the form of the dumpy with the adjustability of the Y. Of these there are two kinds, both of which are built by Messrs. T. Cooke and Sons, York, and have been largely supplied to the Government of India.

The first is Cooke's Patent Reversible level, which is

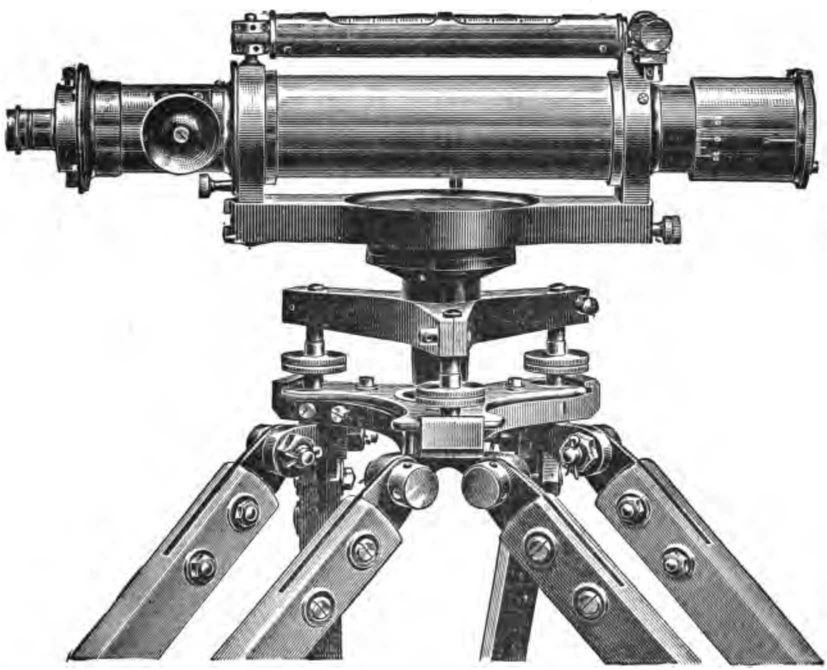


FIG. 51.

shown in Fig. 51. In this instrument the telescope is double. By loosing a screw near the diaphragm, the inner tube can be extracted and reversed, by being inserted at the opposite end, or else revolved on its axis, thus affording all the adjustments of the Y level.

The only drawbacks to this system are—first, a

certain small increase in weight; secondly, the operation of withdrawing and replacing the tube without shaking the stand, is by no means easy to effect, without the exercise of considerable care.

The second form is Cushing's patent, Fig. 52, in which the eye and object ends alone are interchange-

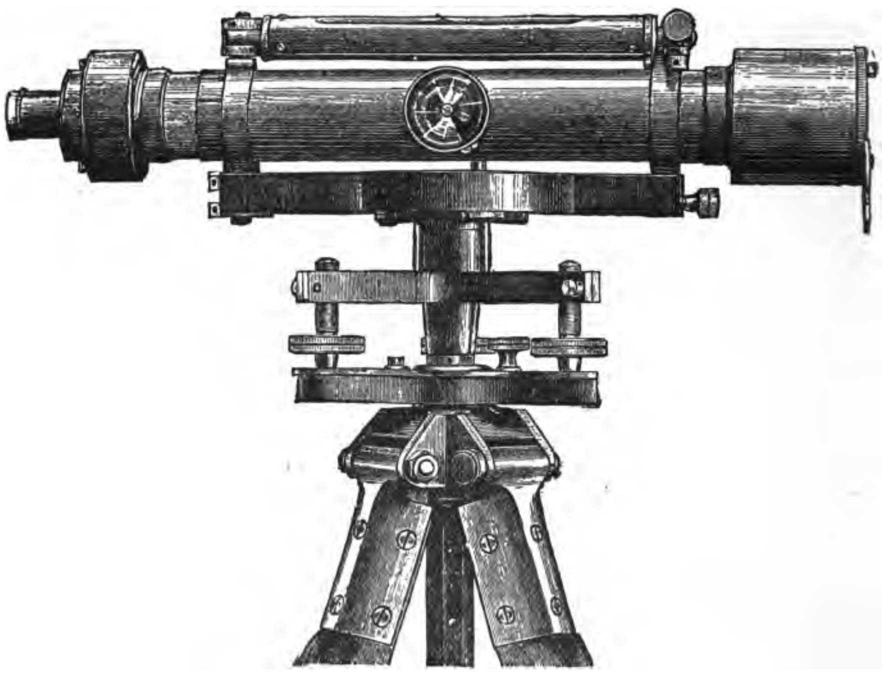


FIG. 52.

able. The eye end, including diaphragm which is built wide to fit in the object end, can be extracted and inserted the opposite side; same with the object end. There being less to move and only one socket fitting required, the adjustment is somewhat easier than in the last case.

The Cushing level is also made by Stanley, but the cost is greater. It is open to doubt whether this is really an improvement on Cooke's method. Messrs. T. Cooke and Son charge the same price for both levels, but the finish of their own patent is admittedly much the better. This throws the balance in favour of the former.

Among so many excellent models by good makers, it is difficult to decide which is the best. The instruments are probably equally good, and the choice must rest on individual preference or caprice. The Author himself prefers a Y level to a dumpy, but is of opinion that the Hoffmann head should be supplied to all levels in lieu of the tribrach. The Charlton model level if mounted on the Hoffmann head would be difficult to beat.

All levels can be fitted with stadia lines or hairs so as to measure distances. For real precision an anallatic lens should be fitted as an extra to the level which is supplied with stadia hairs, otherwise a certain distance, about 2 feet, has to be added to each distance read by the wires. The addition of the so-called anallatic lens corrects this defect.

The ordinary type of level is always at a disadvantage when the ground is sloping. To overcome this difficulty, which causes a loss of time, a variation has been made in the stereotyped design, which permits the telescope to be inclined. One of these is Stanley's Patent Gradiometer, an excellent combination of the level and clinometer, illustrated in Fig. 53.

The following description is supplied by the maker. "This instrument is designed for taking vertical inclines

at fixed small angles for railway, drainage works, &c., by means of an open extended scale which may be conveniently and distinctly read without the use of a vernier. In general construction, as regards telescope

FIG. 53.

stand, &c., it resembles a dumpy level, and will perform all the duties of one of the best when set at zero. The gradiometrical arrangement is effected by the telescope being mounted in trunnions, one being adjustable vertically, the amount of elevation or depression being indicated by a drum graduated to read rise or fall from 1 in 10 to 1 in 1200. By its use a great saving of work is effected. For levelling on steep inclines it saves a great number of settings up. The gradient of the total distance can be taken, and also the distance by stadia reading, and by reference to a gradient table the difference of level can at once be seen. Telemetrical readings at great distances can also be taken by this instrument."

The price of this instrument is 20*l.*, which is decidedly reasonable.

The Author's Level and Road Tracer, illustrated in Figs. 41 and 42, is capable of performing the same functions as the Gradiometer just described, but is probably inferior in precision. Its rôle, however, is different. It is intended, primarily, as a road tracer, for which purpose lightness, portability, and the vertical adjustment of height of instrument are essential.

The next illustration, Fig. 54, is of Short's Gradient Telemeter, a new instrument of very ingenious construction, and of great value.

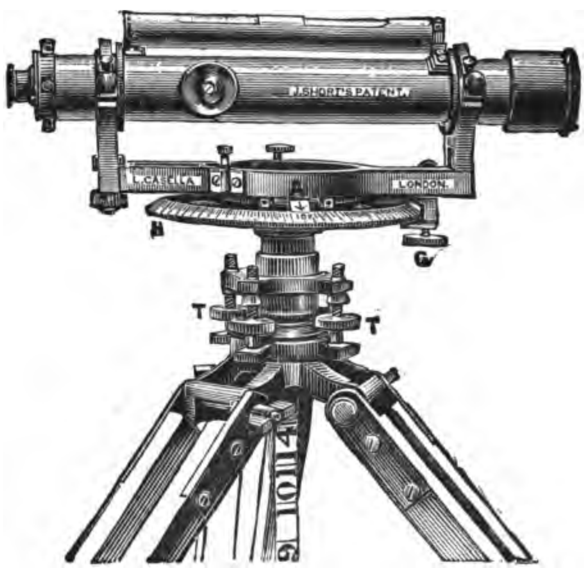


FIG. 54.

The following description is furnished by Mr. L. Casella, the sole maker :—

"This instrument, an illustration of which is shown above, is constructed for getting linear distance, gradi-

ents, and difference in level of objects, all of which it does by one and the same observation, and does away with the necessity for using the land chain or tape. It performs these operations with singular accuracy and ease to the observer, enabling a *much greater* quantity of work to be got through in the same space of time, compared with the usual methods employed by engineers and surveyors. The linear distances can be obtained far more accurately than with the land chain; and this, regardless of rough or broken ground, or the existence of a stream or other water, between the observer's station and the distant object.

Description of the Instrument.

"This Gradient-Telemeter Level is generally similar in its construction to the Dumpy or Y Level, familiar to engineers and surveyors, but, with the addition of a *horizontal* limb or circle H, on which are marked the gradients from 1200 to 10, or any other series of gradients determined on. The gradient marks or points are such a distance apart on the horizontal limb H, that they can be easily read at the index A without the aid of a reading microscope, and being read by an index point—*not* a vernier—the gradient of the distant object is seen at a glance, without the trouble of any calculation; this, together with the fact that the same observation which gives the gradient also gives the *distance* of the observer's station from the object, enables accurate levelling work to be done in a singularly short space of time.

"The telescope of this Gradient-Telemeter Level has an objective $1\frac{7}{10}$ inch aperture, with erect and inverting eye-pieces, as may be preferred for different work; the index A is fixed to and moves with the telescope, and by the *special* construction of the instrument, the horizontal motion of the telescope is converted into vertical dip, or elevation, so that the gradient and distance of objects are obtained by the readings on the horizontal limb H as stated above.

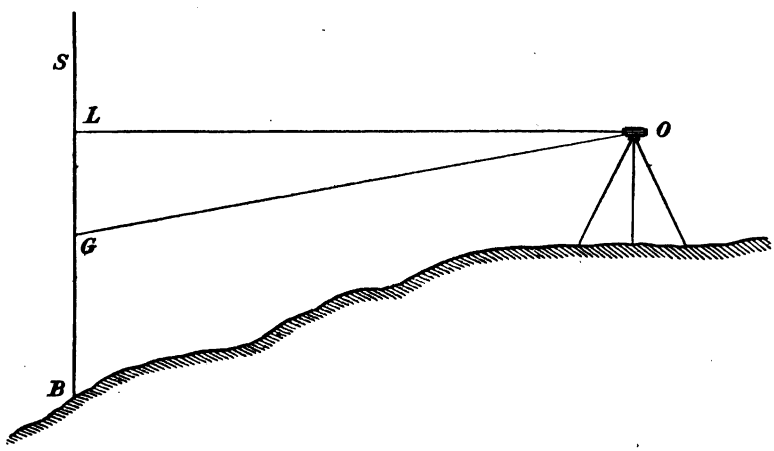
"A light and strong open framework tripod stand is provided with the level, enabling it to be set up on the ground in a very firm manner. A short tape is suspended from the bottom of the instrument, giving the exact height of the centre of the telescope from the ground.

Method of Working with the Gradient Telemeter Level.

"*For taking Gradients.*—The instrument having been set up on its tripod stand in the manner of levels, or theodolites, the index of the instrument must be clamped at zero on the graduated limb, and then levelled in the usual way by the four milled-head levelling-screws T T, and the spirit-level which is fixed to the telescope. While this levelling of the instrument is being done, the axis or centre attached to the graduated horizontal limb H must *alone* be used; the instrument must not be rotated on the axis attached to the telescope. There are two centres or axes to this instrument, an inner and an outer one, as with a theodolite; the *inner* axis

is fixed to the telescope and the movable index which reads the graduations, i.e. the gradients or slopes that are marked on the horizontal limb of the instrument, and the *outer* axis is fixed to the horizontal limb. There is a clamp at G for fixing these two centres or axes, so that motion is got only by the axis of the horizontal limb H.

"Supposing the gradient or slope is required between the two stations O and B, as in the figure, the instrument is set up at O, the station of the observer, and levelled



as described above, and the height of the centre of telescope from the ground is then read at the tape hanging from the base plate of the instrument (suppose this height is 4 feet 9 inches). A levelling or station staff S, is then held upright at the station B, the telescope directed to it and the reading taken. If the reading on the station staff S is identical with that of the tape below the instrument, i.e. 4 feet 9 inches, the two stations O and B would consequently be level;

if the reading on the staff S differs from that on the suspended tape, loosen the clamp screw G which fixes the two axes of the instrument, and holding the telescope lightly with one hand, move the graduated horizontal limb with the other (by means of the ribs or radial bars on its under surface) until the cross wire of the telescope *exactly* cuts on the station staff S the same reading or height (4 feet 9 inches) which is given by the suspended tape at the base-plate of the instrument.

"The index A attached to the telescope will, during this operation, have moved on the graduated limb of the instrument, and, on the index being read, the gradient or slope—say 1 in 160—between the two stations O and B will at once be given without *any calculation whatever*.

"There is a screw attached to the clamp G which gives a fine adjustment, and enables a very exact reading of the station staff S to be taken when required.

"The gradient or slope is given by this method apart from any consideration of distance between the two stations O and B, whether the distance is long or short.

"In this example the ground at station B is supposed to fall from that at the position of the observer at O, and a *falling* gradient is given; if the ground should *rise* at station B the telescope must be reversed in the Y's, so that the object end of the telescope is next the clamp screw G, when the result will be given that the gradient (a rising one) of the station B will be read on the graduated limb of the level; or a *rise* or *fall* is

learned by noting the word "RISE" or "FALL," which is engraved at the ends of the stage on which the Y's are fixed, the engraved word next the eye-end of the telescope always denoting whether the distant station has a *rise* or a *fall.*

"In this relation a remarkable property of the instrument now comes in force, that is, that gradients of distant stations can be learned at one observation and setting up of the instrument, even when the vertical interval (the fall or the rise) of the two stations is as much as 90 feet or 100 feet, or on the instrument being placed *between* two stations, vertical intervals of nearly 200 feet can be learned in a few minutes, by the readings of an ordinary 14-foot levelling staff.

"From the above example the great advantages of this instrument will readily be seen for setting the gradients on railways by this simple and rapid process, or learning those which are already formed, and marking them, no chaining or measuring of distance being required. For irrigation purposes and for contouring it is equally applicable, and engineers and surveyors will readily see many extensions of the usefulness of this gradient telemeter level in actual field work.

"*For Measuring Distances.*—The instrument having been set up and levelled, as in the preceding example for taking gradients, not forgetting to keep the index clamped at zero—required the distance between stations O and B, as in the figure. The station staff S being the usual 14-feet or 16-feet staff divided into $\frac{1}{100}$ths of a foot, take the reading of this staff at station B and suppose it to be 10 feet 68 dec. Then unloosen the

clamp G as in the preceding example, and move the telescope until the index point reads *exactly* on the graduated limb, and fix it there by the clamp G; then move the telescope round on the outer axis of the instrument until it again reads the staff—suppose the second reading to be 6 feet 43 dec.—then we have two readings:—

	ft. dec.
1st reading	10·68
2nd „	6·42
Difference	4·26

and the distance between the two stations O and B is 426 feet; that is, eliminate the *decimal point* from the difference of the two readings, and the figures *as they stand* give the distance exactly in feet without any calculation whatever.

"Another example of this method is to fix the index at the graduation 50 on the limb of the instrument, and divide by 2, the difference of the two readings of the staff, thus, if the readings were as follows:—

	ft. dec.
1st observation	13·82
2nd „	7·34
The difference divided by 2)	6·48
	3·24

On eliminating the decimal point the result would show that in this instance the two stations would be 324 feet distant from each other.

"A valuable extension of this method is to use other gradients, thus:—

Gradient	$33\frac{1}{3}$,	and divide the difference		by	3.
„	25	„	„	„	4.
„	20	„	„	„	5.
„	$16\frac{2}{3}$	„	„	„	6.
„	$12\frac{1}{2}$	„	„	„	8.
„	10	„	„	„	10.

"By the use of these gradients any error in distance resulting from an incorrect reading of the staff is *reduced* respectively to one-third, one-fourth, one-fifth, one-sixth, one-eighth or one-tenth only, from what it would be when working with the 100 gradient.

Note.—It is of the first importance, when working with this instrument, that staff readings are *always* taken exactly between the two vertical wires of the telescope, otherwise serious errors may occur in linear distances or in gradient results.

"A further extension of this method and principle, and one which in the opinion of some engineers makes this instrument the most valuable in existence for certain work, is entered fully into in the following paragraphs.

"This special property and work relates to getting levels from 90 to 100 feet with the ordinary 14-foot staff, without moving the staff or the instrument, and also *horizontal* linear distances by the same observation.

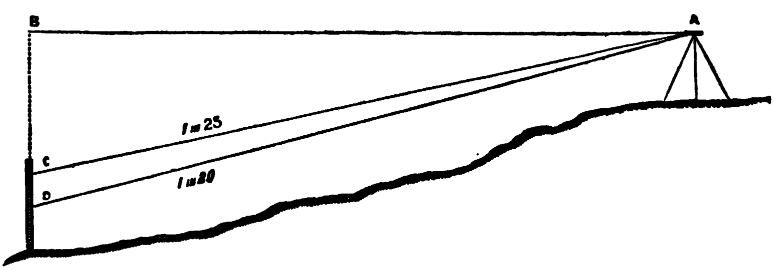
"It will be readily understood that the French metre staff can equally as well be used as the English foot, or any other scale whatever, always providing that the staff is divided decimally.

"Method of getting horizontal linear distances, and also levels up to 90 feet and 100 feet on sloping ground,

when the levelling staff is wholly below or above the horizontal line of sight—without moving the staff or the instrument, with

The Gradient-Telemeter Level.

"*Method and Example.*—When the instrument is levelled and the horizontal line of sight A B is above the top of the 14-foot staff, proceed as follows: Loosen the clamp and move the telescope until the index reaches gradient 100, and sight the staff; if the line of sight



is still above the staff, move the telescope and index farther until the *upper* part of the staff is visible through the telescope. Suppose the index is then near gradient 28, move it again until it cuts exactly gradient 25, and take the staff reading at that gradient—suppose this to be 13·86 feet.

"Then move the index on to G 20, and again read the staff—let this reading be 8·45 feet, and take their difference thus:—

$$
\begin{aligned}
G25 &= 13\cdot86 \\
G20 &= \underline{\ \ 8\cdot45} \\
\text{Difference} &= \underline{\underline{\ \ 5\cdot41}}
\end{aligned}
$$

"Eliminate the decimal point and the *horizontal*

linear distance A B, as in above illustration, is 541 feet, without any calculation being necessary for hypothenusal difference or for other reductions.

"Any pair of gradients in the list below will give by the difference of their readings the *horizontal* distance in this manner—the choice of gradients being determined by the nature of the ground.

"The level of the station B is got by adding $\frac{1}{20}$ the linear distance (27·50 feet) to the staff reading at G 20 (8·45 feet). The level of the distant station is therefore 35·95 feet less the height of the instrument from the ground at station A. The gradient of station B is got without calculation by reading the staff at that station, as explained before.

"If lower gradients than 20 and 25 are used, levels up to nearly 100 feet can be taken.

Gradient Pairs.

G 100	$66\frac{2}{3}$	60	50	$33\frac{1}{3}$	25	20	$12\frac{1}{2}$	$11\frac{1}{9}$
G 50	40	$37\frac{1}{2}$	$33\frac{1}{3}$	25	20	$16\frac{2}{3}$	$11\frac{1}{9}$	10

"Any pair of these gradients being used the difference of their staff readings gives the linear horizontal distance.

"Any gradient and its half being used, gives the higher figure as multiplier for the difference of the two readings, thus giving in another manner the horizontal distance.

G 80, G 40	gives 80 'multiplier.'	G 70, G 35	gives 70 'multiplier.'
G 60, G 30	" 60 "	G 50, G 25	" 50 "

G 40 } G 20 } gives 40 'multiplier.' G 30 } G 15 } gives 30 'multiplier.'

G 20 } G 10 } " 20 "

"The explanation of this rule is as follows: Let G 40 and its half G 20 be taken as examples. Assume the staff reading at G 40 to be 13·86 feet, and the reading at G 20 to be 8·45 feet—the difference of these readings would be 5·41 feet, this amount multiplied by the higher figure G 80 gives 432·80 feet, thus:—

$$\begin{array}{r} 5\cdot41 \\ 80 \\ \hline 432\cdot80 \text{ feet} \end{array}$$

and the horizontal distance from the instrument to the staff is, in this case, 432·80 feet.

"It will be seen on inspection that the reading at G 80 gives a vertical depth from the horizontal line of $\frac{1}{80}$ part the horizontal distance, and in a like manner the reading at G 40 gives a vertical depth of $\frac{1}{40}$ (or $\frac{2}{80}$) of the horizontal distance; their difference will necessarily be $\frac{1}{80}$ of the horizontal distance, and the higher figure 80 being used as a multiplier, will give the resulting distance as 432·80 feet.

"The motive in this example is that $\frac{1}{40} = \frac{2}{80}$, and the difference $\frac{1}{80}$ requires 80 as a 'multiplier' to resume the full horizontal distance 432·80 feet.

For Setting Out Distances by the Subtense Method.

"*Rule.*—If any two integers whatever be taken, and used as divisors into the distance required, the result

will be a gradient pair which, on being worked with, will give on the levelling staff a subtense in feet that is equal to the difference between the two integers selected.

"*Example* (selected integers 5 and 10):—

$$\text{Distance } 315 \div \text{integer } 5 = 63$$
$$\text{,,} \quad 315 \div \text{ ,,} \quad 10 = 31\tfrac{1}{2}$$

$$\text{Distance} = 5, \text{ giving subtense 5 feet.}$$

"*Method of Work.*—(Working with gradients 63 and 31½.) Set up the instrument as usual and send out the levelling staff in the direction of the required line. Move the index of the instrument to G 63, and read the staff; assume this reading to be 5·86 feet, then move the index forward to G 31½, and again read the staff. If the distance from instrument to staff is *exactly* 315 feet, the second staff reading will be 0·86 feet, i.e. give difference 5·00 feet between the two readings. If this second reading is more or less than 0·86 feet, the staff must be signalled farther or nearer, until the difference of the two readings is *exactly* 5 feet.

"The greater the subtense used, the more accurate will the 'setting-out' be, and in *all* cases the nearer to the foot of the staff the two readings are taken, the more correct will the line 'set-out' be.

"If the staff readings are carefully taken, distances can be 'set-out' by this 'subtense' method with at least as much accuracy as best chaining—of course much quicker and across water or rough ground where the chain cannot be used at all.

"Distances thus 'set-out' are always horizontal

distances, no matter what the rise or fall of ground may be.

"It is best to select such integers as divisors that give gradients below G 100. As a rule gradients between G 10 and G 60, give the best and quickest results.

TABLE WITH EXAMPLES OF SUBTENSES FROM 4 FEET TO 10 FEET, FOR DISTANCE 315 FEET.

For Sub-tense.	Integers as Divisors.	Examples Selected.	Resulting Gradient Pairs.	Giving Subtense on Staff.
				feet.
4 ft.	Any two, 4th in succession	5 and 9	63 and 35	4·00
5 ft.	„ 5th „	5 „ 10	63 „ 31½	5·00
6 ft.	„ 6th „	9 „ 15	35 „ 21	6·00
7 ft.	„ 7th „	5 „ 12	63 „ 26¼	7·00
8 ft.	„ 8th „	6 „ 14	52½ „ 22½	8·00
9 ft.	„ 9th „	6 „ 15	52½ „ 21	9·00
10 ft.	„ 10th „	10 „ 20	31½ „ 15¾	10·00

For Taking Levels and Gradients, and Measuring Distances at the same time.

"The gradient telemeter level having been set up on its stand and accurately levelled by means of the four levelling screws T T, and the height of the telescope from the ground at station O (see figure on p. 94) having been read at the suspended tape under the instrument—take this height as 4 feet 9 inches—the usual method of observing station staves at any forward or back stations is then adopted, and their difference

from 4 feet 9 inches (the height of the telescope at the observer's station), is consequently the difference of their levels from the station of the observer.

"The levels of any stations thus having been taken as usual with levelling instruments, the distance of any one or all of the stations is got by either of the two methods explained previously, and this can be done in a *few minutes* without the observer troubling to move from the instrument, and without the trouble of signalling to the staff-holder, or any operation whatever, except loosening the clamp G, and moving the telescope round so that the index reads the graduations on the limb, which give the distance in feet. The distance having thus been taken without any calculation whatever, the telescope can *instantly* be moved back to the zero point, and the instrument is once more level for all the usual purposes of levelling.

"The same observation which gives the level of a distant station, and one other observation which will occupy a minute or less while the clamp G is loose, will also give the gradient or inclination between the station of the observer and the distant station—as explained under the head 'for taking gradients.'

"This rapid and easy manner of learning or of fixing gradients of distant objects, or stations, will commend itself to engineers and surveyors as being of singular value for the many cases in actual field-work where the slope or gradient alone is required, apart from the considerations of distance or level.

For Setting out Railway Curves.

"This is effected by combining a theodolite horizontal limb with the gradient limb of the instrument, which can easily be done; the tangential angles of different points on the curves are then got by the *same observation* as the distance of these points from any given station."

FIG. 55.

This instrument has been supplied to and highly reported on for accuracy combined with labour-saving capacity by the Indian Government, West Australian Government, Cooper's Hill College, Manchester Ship Canal, and London C.C. The price is: 14 inch, with compass, graduated to gradient 1 in 10, 22*l.* If provided with theodolite limb; 14 inch, extra, 11*l.* 10*s.*; 16 inch, 13*l.*; shifting base plate, extra, 3*l.* 10*s.*

Another cheaper form is illustrated in Fig. 55, and is termed the Gradient-Telemeter Dumpy Level. The

gradients are from 1 in 40 to 1 in 500, so it has not the range of the former pattern. The arc is graduated on brass, not silver. The price is: 12 inch, 15*l.* 10*s.*; 14 inch, 18*l.*; 16 inch, 14*l.* 10*s.*; compass extra, 1*l.* 10*s.*

Still another form of this instrument is given in Fig. 56, viz. the "Gradient-Telemeter Mining Dial." It ranges from 1 in 24 to 1 in 500. The Author is of

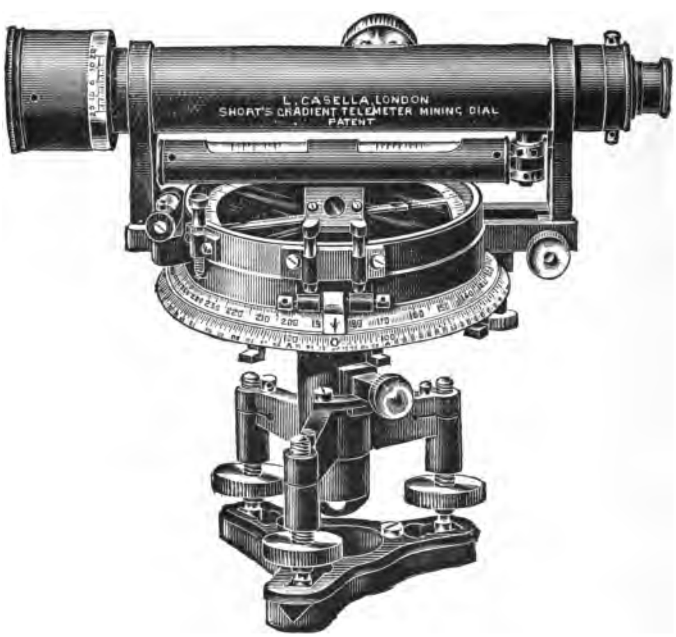


FIG. 56.

opinion that a combination of this form and that of Fig. 54 would greatly enhance the scope of utility of this instrument, viz.

1. The telescope to be as in Fig. 54, but raised higher.

2. A large dial to be substituted for the prismatic compass in Fig. 56, with needle.

3. The gradient to be from 1 in 10 to 1 in 500 with outside horizontal circle fixed, as in Fig. 56.

4. Hoffmann head with vertically adjustable base, as in Fig. 41, to supplant the tribrach.

5. The dial and vernier readings to correspond as in Improved Hedley.

Thus modified, this level would, in the Author's opinion, be the best all-round instrument for engineering operations ever designed, as it combines so many excellencies, and its range of utility is greater than that of any other—embracing the functions of the level, miner's dial, theodolite and tacheometer, in addition to its own invaluable speciality of minimising labour in the field as well as the office. These alterations would probably increase the price to 30*l.* or over, but would be well worth the additional cost. The price of the Gradient-Telemeter Mining Dial, Fig. 56, is, 14 inch, 24*l.* 10*s.*

For further remarks on suggested modifications of this instrument, see Appendix.

CHAPTER VI.

BAROMETRICAL LEVELLING.

THE Aneroid Barometer, Fig. 57, is largely used for preliminary levelling operations in the East and in the Colonies. Instruments are now made to read with vernier to one foot of elevation.

The general fault in all aneroids is that the range is unnecessarily great. It is not everyone who wants to ascertain the height of mountains 10,000 feet high, or to descend into the bowels of the earth down a mine shaft, and yet we find that no surveying aneroid is made with a less range than 6000 feet. The Author has had two instruments made by Mr. W. H. Harling, having a moderate range, viz. from sea level to 3000 feet, or from 27 to 31 inches of mercury. This ensures a cheaper instrument and larger graduations. An extra thousand feet is allowed for play of the needle, so that the graduations extend to 4000 feet. In all aneroids, 31 inches of mercury is taken as atmospheric pressure at sea-level, whereas 30 inches would be more generally correct. The former represents the maximum possible pressure, which is hardly ever attained in practice.

The aneroid barometer is a very delicate and uncertain instrument, but by the methods enumerated below its vagaries can be curbed, or rather modified, to useful purpose.

Surveying aneroids have two sets of concentric graduations, the inner giving the air pressure or inches of mercury, and the outer the elevation above sea-level due to the diminishing pressure. The elevations marked are purely theoretical and are seldom if ever in accordance with the actual height above sea-level. This marked discrepancy, however, by no means interferes with the approximately correct rendering of relative levels.

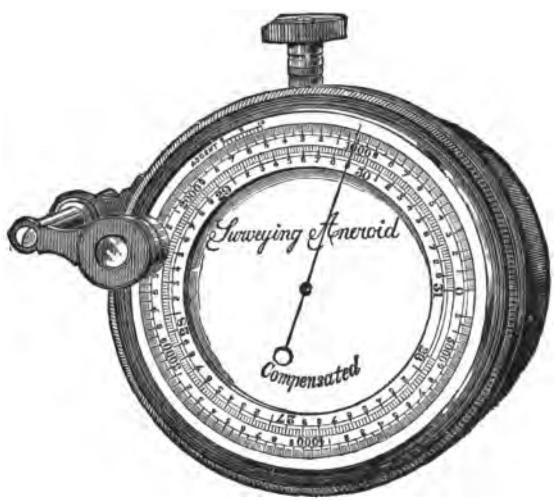


FIG. 57.

The observer starts from a bench mark, whose height above sea-level is known. It does not at all follow, that this known elevation corresponds, within several hundred feet, with that registered by the instrument, but this is taken as a back-sight, and all subsequent observations are relative to it.

The needle is not only affected by increase or diminution of pressure, due to difference of elevation,

but is sensible to variations of pressure, due to barometrical changes in the weather. In addition to this, the so-called diurnal wave has to be considered, and further still, the idiosyncrasy of each individual instrument.

The diurnal wave has a small range in high latitudes, but is very considerable in low latitudes. In England the extreme range is about 22 feet, in India 140 feet. This of course with a steady barometer. In hot, dry climates the barometer remains very steady for several months on end, whereas in England the climate is so changeable that the variations are very great; this is exclusive of the diurnal wave. For levelling operations, twin aneroids should be used, each of which should be an exact copy of the other, or as near as possible. The *modus operandi* is for one aneroid to be read by an observer, who is stationary at the survey camp while the other is taken out. The needle readings of the stationary aneroid, are carefully read by the vernier, at every half or quarter hour, and noted opposite the time by the clock or watch. Thus for the whole day, the variations of the needle are noted, and a table formed, which shows the additions or deductions in feet to be made by the outdoor observer.

The following example will explain the method of working. The levels are started from a B.M., the height above sea-level of which is approximately known. Say this is 1305 feet. At 6 A.M. work is started. The aneroids placed on the B.M. or some known height above it read 1400, giving a deduction to be made of 95 feet from the first reading.

The outdoor worker leaves, and every level taken is noted by him in feet in the level book, all levels being treated as intermediates, except the last, from which work will be continued next day. Opposite each reading the time will likewise be noted, and two columns left for + and − addditions or subtractions to and from the readings.

No.	B. S.	Int.	Fore-sight.	Time.	+	−	Reduced Level.	Bearing.	Distance.
0	1400			6 a.m.		95′	1305		

The remaining pluses and minuses are taken from the home operator's book at the nearest corresponding time, and thus the whole day's readings reduced to the correct level. The last reading should be noted in the fore-sight column, in order to distinguish it, and a peg should be driven down and the place well noted. Next day this fore-sight becomes the back-sight for the following operations, the camp being probably moved on for convenience, to be near the B.M. The difference of level of the table on which the stationary aneroid is placed, and the B.M., is easily ascertained; the table elevation of the stationary aneroid will then form the real back-sight of the day's levelling.

The stationary operator, as already observed, notes the ascertained correct R.L. of the table on which the aneroid is placed, and that read by the instrument at each half or quarter hour, and the differences between

the actual reduced level, and the various readings during the day, are those copied into the plus and minus columns of the level book. It will thus be seen that the barometrical readings of the aneroid are ignored, only the corresponding elevations being read.

In case only one instrument is available, the following method is adopted, which is by no means so correct as the foregoing. It is assumed that the same barometrical conditions exist for several days or a month after the observations. The aneroid is first read at intervals of time for three consecutive days. A chart is then prepared of any convenient scale, vertical lines representing the half or quarter hours, and horizontal lines the scale of elevations in feet, say, each space in the horizontal lines is equivalent to 5 feet or 10 feet, the vertical lines being assumed half an hour apart. The readings of the aneroid in feet are noted in a book against the time, just as before, for three days, each day's record being plotted on the chart with different coloured inks. When this is done, the diurnal wave is sketched on the same chart, being the average of the three recorded, and this last is assumed to be the correct diagram. From this, by measurement, a table of + and − is prepared for entry in the level book at the corresponding time of day, for use in all subsequent operations.

The want of a self-recording barograph recording heights, as is done by the human operator, in the first instance, is much required. This would release one skilled operator and, being automatic in action, be free from possible error. Many recording barometers are

made, but they are all for meteorological purposes, and are mostly for sea-level or near it. They can be made to order for any required elevation, but for such minute reading as is required in a surveyor's aneroid, and with a range of several thousand feet, the instrument would be immensely bulky and very expensive; in fact, no such instruments are made.

The ordinary type of Barograph is shown in Fig. 58.

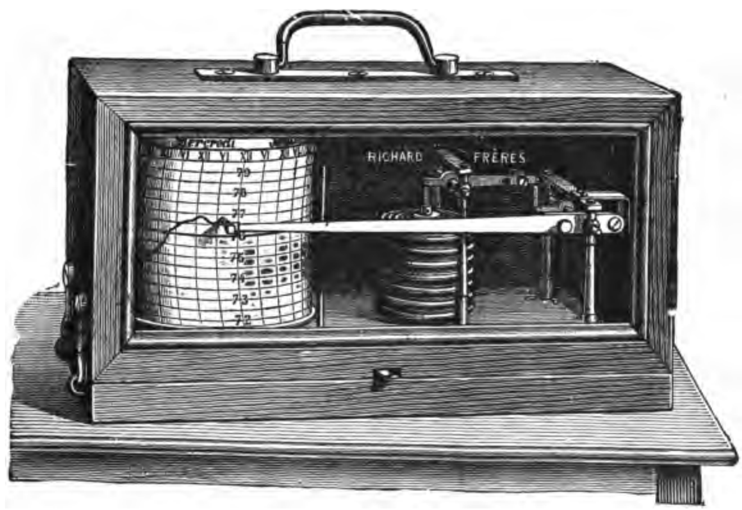


FIG. 58.

They are made in Paris by the celebrated firm of Richard Frères. The figure is furnished by Mr. L. Casella, who stocks these instruments.

The Author has devised an instrument, which it is believed will meet all requirements, and besides be portable and comparatively inexpensive. The invention is being patented, but the instrument itself has not yet been actually built; consequently an illustration

cannot be given; the following diagram, however, will be sufficient to explain its working.

N.B.—It is essential that the portable aneroid used with the barograph correspond closely with it, and the two should be specially ordered together from the same maker.

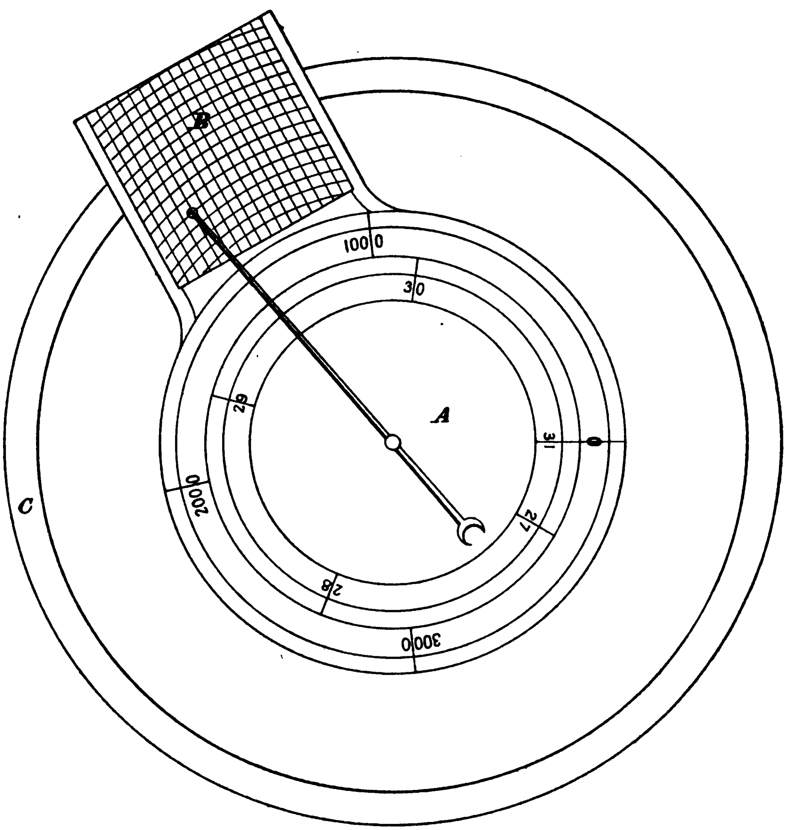


FIG. 59.

In Fig. 59, A is the ordinary circular surveying Aneroid reading, with vernier to single feet, 4½ inches or 5 inches diameter, range not recommended over 3000

to 3500 feet. B is a clockwork arrangement (attached to the body of the case by a circular ring), which communicates motion to the chart. It runs on a wheel or wheels, round a roller path C, fastened to the bottom of the wooden casing. It is moved to any desired position by a rack, formed on the outside of the pathway, worked by a pinion attached to B. The indicating needle is lengthened to pass over on to the chart, where a pointer at its extremity automatically records the needle's movements. The chart is graduated in an exactly similar manner to that shown in Fig. 58. The curved lines are of the radius of needle, and their spacing represents time. The spaces enclosed by the straight lines correspond in width to the graduations on the aneroid, measured along the curve, and consequently represent elevation, but are exaggerated in width as compared with the divisions on the circle, owing to the increase of radius of pointer. The portion B can be set at any position round the aneroid, in correspondence with the position of needle, and fixed by the rack, so that its centre line is exactly in line with one of the 100-feet graduations of the aneroid. Arrangements will be made to throw the chart out of gear when the record is not required, as at night. The chart, when removed, can be read with a vernier scale to single feet or even less, and a table of additions and subtractions framed from it, as before described, for each day of work.

A further improvement, which is likewise patented, and which is applicable to all recording barometers, is as follows. As well known, the indicating needle is

provided at its extremity with a pen, which marks the fluctuations of air pressure on the chart. In the existing types, owing to the friction of this drag on the paper, the needle has to be made a stiff solid bar, and to increase the power of the instrument to overcome this, a battery of vacuum boxes is used, placed one over the other, as shown in Fig. 58. With a free needle, as in the ordinary circular pattern of aneroid, this complication is not necessary, one vacuum case with exceedingly light mechanism being all that is required. The improvement previously alluded to, consists in having a free needle, which will only mark the chart at certain intervals of time, and not continually drag on the paper. This is effected by attaching a spring striker to the clock acting outside, similar to that employed in striking hours, but to the striking end of the lever, a flat bar of the same width as the chart is fixed, so as to bear exactly parallel to the surface of the chart when down. This lever will momentarily press down the end of the free needle, (to which a pricker will be attached) in whatever position it may be on the width of the chart. On the striker flying back into position, the needle will likewise spring off clear of the chart paper. If it is required to register every half hour, this can easily be arranged by ordinary clock mechanism. The intermittent record thus obtained, will be just as good as the continuous line drawn in the ordinary type. This arrangement suffices for the stationary self-recording instrument. As, however, this new type will be quite portable, one instrument could with advantage be taken out by the leveller, thus

obviating any reading in the field. In this case, however, a record is required, not at even intervals of time, but at any moment, when a reading has to be noted. This will be effected by another arrangement whereby the operator himself, by pressing a knob, releases the hammer and thus secures a record.

A further refinement is based on the known property of aneroids requiring a light tap, to shake the mechanism and cause the needle to read correctly. This is absolutely necessary in case of sudden change of elevation, the needle being slow to act. This necessary shake will be provided for by a second striker, which will act a little in advance of the other, which will tap the glass or the side of the case. In the field this second hammer will be released by the operator.

Mr. J. J. Hicks, of Hatton Garden, will probably undertake the manufacture of this instrument.

The mercurial barometer is in some ways a more reliable instrument for elevation, than the aneroid, being much less sensitive. The absence of this qualification, however, militates against its use for very small differences of pressure. It likewise is modified by capillary attraction and temperature, the aneroid being compensated in the latter point. Hence the thermometer has to be read in conjunction with the mercurial barometer, and the recorded pressures modified accordingly. This detracts from the practical utility of the instrument for surveying purposes.

The usual hill barometer is a ponderous instrument, necessarily of great length. The most modern develop-

ment is Collie's patent portable barometer, manufactured by Mr. L. Casella, London. Fig. 60 represents this in strument.

The following description of this instrument has been supplied by Mr. Casella :—

" The extreme difficulty of carrying to the top of a mountain, not merely a glass tube nearly a yard long,

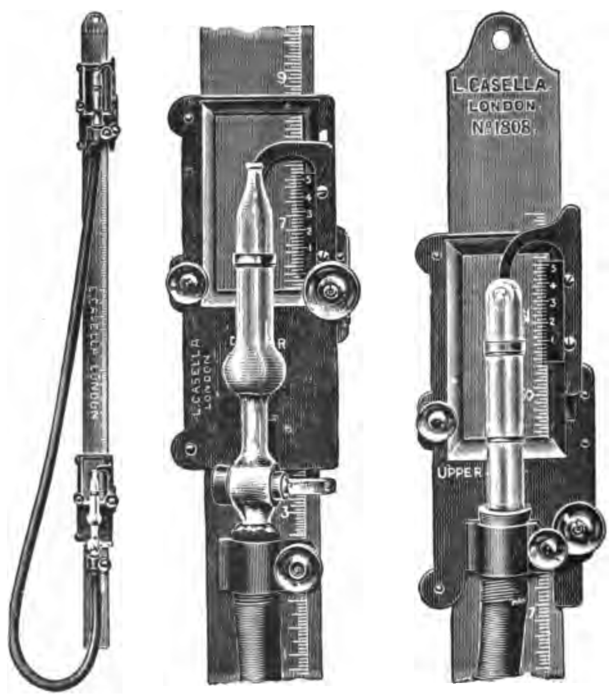


FIG. 60.

but that tube filled with mercury, has been known for generations and has led to innumerable attempts to provide an efficient substitute. Of these, the most successful have been the use of aneroids constructed with extreme care, and of delicate boiling point thermometers.

"Neither of these plans has yet given the precision afforded by a standard mercurial column.

"In the present instrument, there is, strange to say, no long glass tube, merely two short lengths for the two ends of the column, the intervening length being constructed of very stout indiarubber tube specially constructed and selected.

"Inspection of the instrument will alone enable observers to become thoroughly familiar with its niceties, but its broad principles will be readily followed.

"It is in principle a Guy-Lussac syphon, but in principle alone, for it differs in every detail.

"Taking first the scale, this is engraved on a bar of aluminium 40 inches long, 1 inch broad, and stiffened throughout its length by a rib 0·3 inch deep. This secures thorough rigidity, and yet, being of so light a metal, the total weight including the verniers and carriages (which we have yet to describe) is only 21 lb., while the barometer tube, 4 inches in diameter in its glass portions, when filled weighs only 4 oz.

"There is no altitude at which a human being can live where this instrument would cease to work, for it will measure with equal accuracy a pressure of 5 inches, or of 31 inches.

"The tube is carried separately from the scale, and packs in a very small box. The upper portion is provided with a Guy-Lussac air trap, so that the vacuum is kept perfect, and if by any means a little air should be caught in the trap it is easily removed by a small pump which is supplied with the instrument, and is applied

to the portion of tube forming the short leg of the syphon.

"The scale, as we have intimated, bears two carriages sliding on it capable of being clamped rigidly. To make an observation, the scale is suspended vertically and the two portions of the tube are clamped to their proper carriages, the glass tap of the lower one is opened gently and the mercury allowed to rise in that tube. The position of the two carriages on the bar is then so adjusted that the mercury stands within the range of each of the two verniers. This being done, the reading is taken of each vernier, and the difference gives the barometic pressure.

Reading of upper vernier,	31,112	inches
,, lower ,,	1,180	,,
True barometric height,	29,932	,,

"On dismounting, the lower tube should be so raised that all the mercury (except a drop the size of a pea) passes through the glass tap into the rubber tube, the tap is turned and the whole is as portable as before.

"The instrument was designed especially for giving readings of extreme accuracy at any required point; this it will do, but it is not intended for use as an ordinary barometer, and should be dismounted after each reading, not left hung up for a week for hourly readings, as in such a case it is possible that the vacuum would not remain perfect."

The Collie barometer reads to ·002 of an inch of mercury, equivalent, roughly, to 2 feet of elevation.

This reading has to be corrected by a table for temperature and likewise latitude. When thus reduced, the readings can be turned into actual feet of elevation, by use of another table. It would be very useful in conjunction with aneroids. Being a standard barometer, the former could be kept adjusted to the mercurial barometer. The price of the Collie barometer is 18*l.*

CHAPTER VII.

TACHEOMETRY.

A TACHEOMETER is simply a transit theodolite fitted with a large achromatic telescope similar to a level, with the addition of stadia hairs in the diaphragm, and further what is termed an anallatic lens. The stadia hairs and lens are frequently added to ordinary levels and also theodolites. The Author has a Davis Hedley dial as in Fig. 12, with long legs, and the telescope fitted with stadia lines on a stop glass as well as an anallatic lens. This greatly increases the range of utility of the instrument, as not only can distances be measured but the instrument is also rendered available for rough levelling purposes. Tacheometers are largely used on the Continent and in America but less so in England. In fact, our great firms supply numbers of these instruments graduated in grades and decimals to the Continent and South America. If properly worked they save an immense deal of labour, combining the functions of theodolite and level. As they can be used for the ordinary purposes of a theodolite apart from other capabilities, they are bound in time to displace the theodolite for engineering operations, that instrument being left to professional land surveyors. The only drawback in the use of the tacheometer is the

trouble involved in the calculations that are required to reduce inclined, to horizontal distances in the case of distance measuring, and the corrections due to the same cause in levelling. By the exceedingly ingenious and effective device of the Short's Gradient Telemeter, already mentioned, these difficulties are overcome by mechanical means, but possibly this would not in some cases be deemed sufficiently accurate. With the ordinary tacheometer, calculations have to be resorted to. These are effected with sufficient approximation by use of a device such as Gillman's Patent Tacheometer diagrams, sold by Messrs. Troughton and Simms (price 7*s.* 6*d.*), or by using a slide rule specially made for this purpose, of which there are several sold, the Fuller-Bakewell slide rule, by Stanley, being recommended.

The formula for reducing inclined distances ascertained by reading the staff to horizontal is

$$D = D' \cos^2 \theta,$$

where D = horizontal distance, D' inclined distance, and θ vertical angle of inclination. The difference of level between the line of collimation of the telescope and the point on the staff cut by the centre wire is

$$H = D' \sin \theta \cos \theta.$$

These formulæ are worked out in the table of stadia reductions given in the Appendix. They are for every second minute from 0° to 27°. Owing to the greater ease of calculation with a decimal system, grades are more in favour than degrees in graduating the horizontal and vertical arcs of tacheometers.

The system of distance measuring by subtense angles will be briefly epitomised. Stadia hairs are horizontal lines, either hairs fixed to the diaphragm or else marked on a stop glass. These are equidistant from the centre horizontal line which corresponds with the horizontal hair in a level. There are thus four hairs, three horizontal and one vertical. Some tacheometers have five horizontal hairs. The upper and lower hairs are spaced by the makers at such a distance apart that the vertical height on the level staff enclosed between them is $\frac{1}{100}$ or $\frac{1}{200}$, as the case may be, of the distance to the staff. With an anallatic lens the difference of the readings of top and bottom stadia hairs is the exact $\frac{1}{100}$ or $\frac{1}{200}$ of the distance apart, but where no correcting lens is used, a certain length somewhat under 2 feet, which is ascertained by experiment, has to be added to the distance thus obtained. The anallatic lens absorbs light, and further, close readings within 60 feet are impracticable, consequently some engineers prefer to dispense with it. The convenience, however, of its use is very great, and tacheometers are made with much more powerful glasses than theodolites or even levels. For large tacheometers the ratio of D to H is generally 1 in 200, for ordinary telescopes 1 in 100 or even 1 in 50. Telescopes for purely telemetrical purposes, not used for levelling, have no centre horizontal hair. The limits of tacheometers or telemetrical telescopes fitted with the anallatic lens is, without 50 or 60 feet, and within to about 1000 feet.

The ordinary Sopwith levelling staff can be used, but for long distances, or with telescopes of but moderate

power, a staff with plainer and coarser graduations is preferable.

For colonial work it is best to have the subtense lines marked on a stop glass. In some tacheometers the hairs are adjustable up or down so that any desirable ratio can be adopted.

This arrangement is hardly to be commended, though adopted largely in America, where the same confidence is not reposed in instrument makers as in England.

Tacheometrical operations, combining as they do levelling and surveying, are by no means simple, and require practice to be worked with ease.

The following description of MM. Porro's and Moinot's method of preliminary railway alignment is excerpted from Mr. Brough's work on 'Mine Surveying,' in which valuable work this subject is dealt with *in extenso* :—

"*The Field-Work.*—Tacheometric surveys are usually conducted by a party of three : (1) the engineer to direct the work ; (2) the observer at the instrument ; (3) the recorder to book the results. On level ground two staff-holders are employed, and on irregular ground one or two more are necessary, in order to prevent loss of time to the observer. For less important surveys one observer and one staff-holder suffice.

"When the instrument has been set up at a suitable point, staff-holders are sent to all the points to be surveyed. To each point a number is assigned, and noted in the field-book, and on a sketch at the same time. The telescope is directed towards the staff, and the micrometer wires are read and noted in the proper

column of the field-book. The horizontal and vertical angles are then read and noted. This operation is repeated for all the points that can be seen from this station.

"In this way, for every point three figures are obtained—the distance, and the horizontal and vertical angles. The point is thus fixed by means of polar co-ordinates.

"If the survey has to be connected with one previously made, some data from the former work are necessary in order to make the connection. Two points, if accurately determined, are sufficient.

"The instrument having been set up and levelled, the engineer makes a reconnaissance of the ground to be surveyed, and gives instructions to the staff-holder, who goes successively to all the points selected by the engineer, and at each one holds the staff steadily vertical until he receives a signal to pass on. The observer at the instrument now makes the necessary observations, which are noted in the field-book by the recorder.

"When the ground to be surveyed is so extensive that two stations are necessary, the engineer selects two points visible from both stations. When the observation at the first station is finished, the instrument is moved to the second, and the two points are observed. The connection would, of course, be made by means of one point only. It is, however, advisable to employ two as a check on the accuracy of the work. When a number of stations are required the method is similar. The method described is that used by Porro.

"Moinot employs the tacheometer in preliminary

surveys for railway lines in the following manner:—Before the belt of ground is surveyed, an extensive reconnaissance is undertaken, and the main direction of the railway determined, so that the survey may be limited to a comparatively narrow strip. On account of the rapidity of the method there is no occasion to be too anxious about limiting the width. A strip should always be selected of sufficient width to allow if necessary a lateral displacement of the line. A width of 400 yards is quite sufficient. Marks are fixed 200 to 300 yards apart, and numbers are assigned to them. For filling in details points are chosen wherever the ground presents any decided change of level. The instrument is set up at a point so selected, that connection can be made with any existing survey or railway. The assistant then gives a signal with a whistle or horn to announce that he is ready. In the meantime the recorder has measured and noted the height of the instrument, and the engineer has made a sketch roughly to the scale of the plan to be prepared, showing all the roads, rivers, boundaries, fields, and the station of the instrument. As soon as he hears the signal, the engineer indicates to each staff-holder his place, care being taken that only one staff is ready at a time. The other staff-holder is still on the road, or, if already at his post, he turns the narrow side of the staff towards the instrument, and remains in this position until it is signalled to him that the preceding reading is finished. He then turns the graduation of the staff towards the instrument, and by means of a signal directs attention to his position. He then awaits the signal that he can pass on.

"The assistant at the instrument has to read the upper and the lower wires with each staff, and then the vertical and horizontal angles, and to call them out in this order to the recorder, who notes them in the field-book. The recorder enters the points in order, as 1, 2, 3, &c. At every fifth or tenth point the assistant gives a double signal, whereby the engineer, although at a distance from the instrument, has a check on the accuracy of the booking, seeing that he has entered the points in his sketch in the same order.

"In order to economise time, the engineer selects the points in such a way that he comes finally in proximity to the point he regarded as being most suitable for the next station. Here he places a mark and sets up a staff, at the same time giving a special signal to the assistant.

"When the readings for this next station are finished the observations at the first station are complete, and the instrument is carried on. In the meantime, the man who was holding the staff at the new station returns to the preceding one just left by the instrument. The recorder begins a new station in the field-book, and at once enters the height of the instrument in its proper column. A back-observation is now taken, and the distance, height and azimuth should coincide with the results previously obtained.

"By the aid of this method, Moinot has surveyed about 1000 miles for railway purposes. The distances, when measured on the ground with extreme care, have never differed from those shown on the plan by more than one per thousand, and the longitudinal section

obtained by accurate spirit-levelling, has never presented any appreciable difference when compared with the results afforded by the heights given on the plan."

The operations above described would be much simplified were a telemetrical theodolite dial (say as in Figs. 12 or 17) used and vernier meridian angles taken. The bearings of the points being thus noted, interpolation will not be required to fix their position.

The combined operations of levelling with inclined telescope and of surveying necessarily involve a large field-book, which at first sight appears rather formidable, twenty columns at least being required. The following table is the form used by the Author on a small survey, the instrument used being Davis's Improved Dial, Fig. 12, with telemetrical telescope.

In this survey no check angles were taken, and the procedure is the same as that described on p. 44, the first method, with this difference, that back bearings are read towards the back-sight, the telescope not being reversed.

The book is kept in the ordinary American style of showing height of collimation of instrument above the back-sight, the English method of having two columns of rise and fall involving, in this case, great complications. The levels it will be seen are in every case first reduced as if the telescope were level. Where the line of sight is inclined, the difference in height due to the grade is added or subtracted as the case may be. The columns which are filled up in the field, viz. A B C D E J K L, should be outlined red, to distinguish them. If an extract from the tabular station reductions for full

A.	B.	C.	D.	E.		F.	G.	H.	I.	
Stations.	Horizontal Angle.	Grade Angle. Up.	Grade Angle. Down.	Stadia Readings. Upper. (a)	Stadia Readings. Lower. (b)	Inclined distance $(a-b) \times 100$.	Tabular Deduction in 100.	Deduction $\frac{F \times G}{100}$.	Horizontal Distance F-H.	Total Distance from Starting point.
B on A	175° 21′	..	5°	3·80	6·40	260	·76	2·0	258·	258
B on *a*	175° 21′	..	5°	7·47	8·97	150	·76	1·14	149·9	..
At B	..	..	..	..	..	..	..	..	..	..
B on *b*	355° 15′	7°	..	4·29	6·04	175	1·49	2·61	172·4	..
B on C	355° 15′	7°	..	5·90	8·90	300	1·49	4·5	295·5	533·5
D on C	174° 39′	..	3°	5·56	8·90	334	·27	·90	333·1	886·6
D on *c*	174° 39′	..	3°	3·30	5·85	255	·27	·61	254·4	..
At D	..	..	..	..	..	..	..	..	..	..
D on *d*	354° 57′	1°	..	0·26	2·37	211	·03	·06	210·94	..
D on E	354° 57′	1°	..	0·01	5·28	527	·03	·16	526·8	1413·4
F on E	174° 12′	level		1·80	6·35	455	..	4·55	450·4	1863·8
At F	..	..	..	..	..	..	..	..	..	..
F on G	114° 21′	1°	..	7·65	12·10	445	·03	·13	444·9	2308·7
H on G	294° 39′	level		0·10	4·30	420	..	4·2	415·8	2724·5
At H	..	..	..	..	..	..	..	..	..	..
H on I	113° 33′	..	1°	5·55	10·35	480	·03	·14	479·9	3204·4

J.	K.	L.	M.	N.	O.	P.		Q.	R.	S.
Back-sight.	Inter.	Fore-sight.	Height of Collimation of Level.	Tabular difference in height for 100 feet.	Height to be added or subtracted $\frac{N \times F}{100}$.	Sense of Grade.	Whether added or subtracted.	Corrected Height of Collimation. $M \pm O$.	R.L. Instrument Level.	R.L. Corrected for Inclination.
5·10	..	..	105·10	8·68	22·56	down	add	127·66	..	100·00
..	8·23	..	..	8·68	13·02	down	subtract	..	121·43	108·41
..	5·04	..	..	..	..	level	..	..	122·62	122·62
..	5·16	..	..	12·10	20·17	up	add	..	122·50	142·67
..	..	7·40	..	12·10	36·30	up	add	..	120·26	156·56
7·23	..	..	163·79	5·23	17·47	down	add	181·26	..	..
..	4·57	..	..	5·23	13·33	down	subtract	..	173·69	160·36
..	4·19	..	..	..	..	..	..	..	177·07	177·07
..	1·31	..	..	1·74	3·67	up	add	..	179·95	183·62
..	..	2·64	..	1·74	9·17	up	add	..	178·62	187·79
4·07	..	..	191·86	..	..	level	..	191·86	..	..
..	5·06	..	..	..	..	level	..	..	186·80	186·80
..	..	9·87	..	1·74	7·74	up	add	..	181·99	189·73
2·20	..	..	191·93	..	..	level	..	191·93	..	..
..	4·64	..	..	..	..	level	..	..	187·29	187·29
..	..	7·95	..	1·74	8·35	down	subtract	..	183·88	175·63

degrees likely to be met with, are noted on a blank page, the rest of the columns can easily be filled up in the field as the operator proceeds.

The following rules govern the reductions of the levels :—

For collimation *add* the back-sight to R.L. of station (col. S) and enter in col. M.

If sight is inclined *up* grade, from M *deduct* O.
" " *down* " to M *add* O.
Enter result in both cases in col. Q.

For R.Ls. of intermediate and fore-sights subtract Inter or F S from col. Q and enter in col. R.

If sight is inclined—

For up grade *add* O to R and enter in S.
" down " *deduct* P from R " " S.

Measured height of instrument above station where instrument is set up, should naturally be treated as a level intermediate sight.

The back-sight observations must have a line to themselves—not on the same line as the last fore-sight.

The measurement of the height of line of collimation above the peg on which the tripod stands, cannot well be done with the level staff. To obviate this difficulty and obtain an accurate result, the plumb-bob hook should be made wide and flat so that a tape can be passed over it, and further, it should be fixed by the instrument maker at a definite distance in feet below centre of telescope. A specially prepared short tape,

subdivided in a similar way to the level staff, is then passed over the hook and drawn up till the end, which should be a flat brass disc, just touches the surface of the peg; the tape reading added to the known constant will thus give the height required with absolute precision. This arrangement is adopted in the Gradient Telemeter.

The use of the Tacheometer is particularly labour-saving in the case of a tract traverse on rough ground, with cross sections at intervals. In such a case the alignment of the direction of the cross sections at right angles or otherwise to the traverse line, can be set out by a cross staff or optical square. The intersecting meridian angle taken from the instrument, will then fix these points, without the necessity of stadia readings.
can be
n to the
letters.
s are re-

Page 132, line 15—*for* P from R *read* O from R

quired on each side, then those on the right can be designated n′ n″, and so on, and on the left n^1 n^2 n^3, or else by using the corresponding Greek letters on one side. If the stations are designated by numbers, say 41, the corresponding right and left points can be distinguished as 41^a 41^b right, and 41^z 41^y left, reversing the alphabet. It will be found necessary to adopt some such device, to ensure perspicuity. A sketch plan of the traverse and a large column for remarks are likewise essential to prevent confusion.

The Gradient Telemeter of the modified form suggested in p. 106, combining a dial with its other admir-

able features, is so markedly superior in its mechanical arrangements and ease of working to the ordinary tacheometer, which is but a glorified theodolite, that it is bound to supplant the latter with all intelligent practical workers for engineering operations.

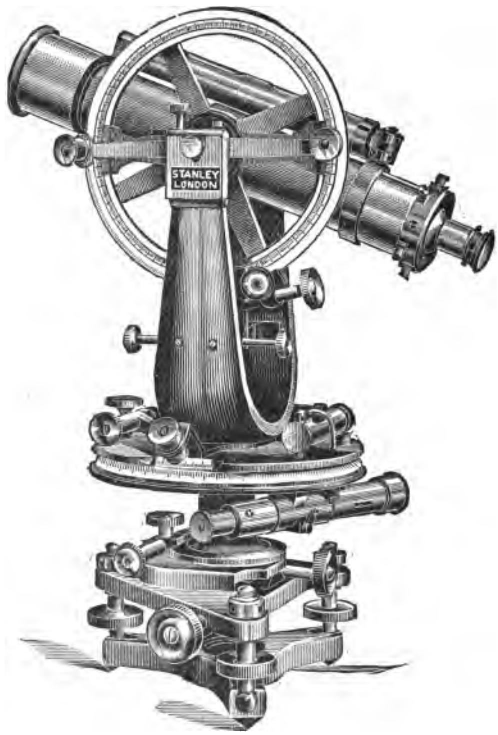


FIG. 61.

We will proceed to give illustrations of Tacheometers by various makers.

Fig. 61 is Mr. W. F. Stanley's form, of excellent construction. The needle is read through a microscope fitted on the side, instead of the usual box needle read by the eye, which is liable to minute error.

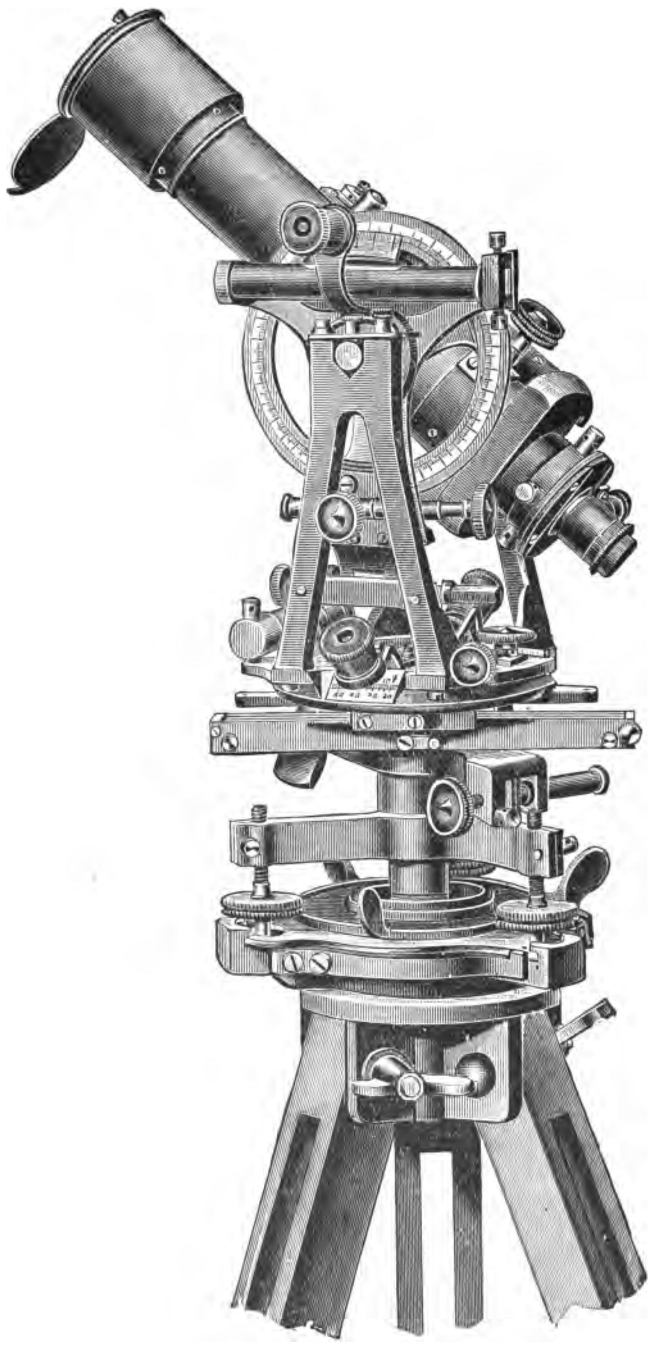


Fig. 62.

Figs. 62 and 63 represent two styles by Messrs. Troughton and Simms, a firm of world-wide reputation.

Fig. 64 represents a magnificent Transit of large size by Casella. This instrument is shown with a

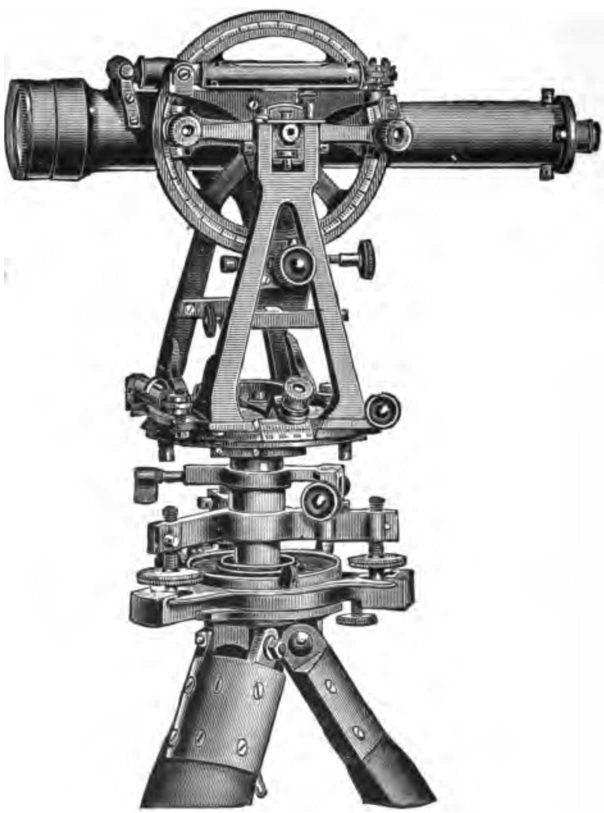


FIG. 63.

theodolite telescope. When fitted with a larger one it becomes a tacheometer. It is of particularly rigid construction.

Fig. 65 illustrates Davis and Son's form.

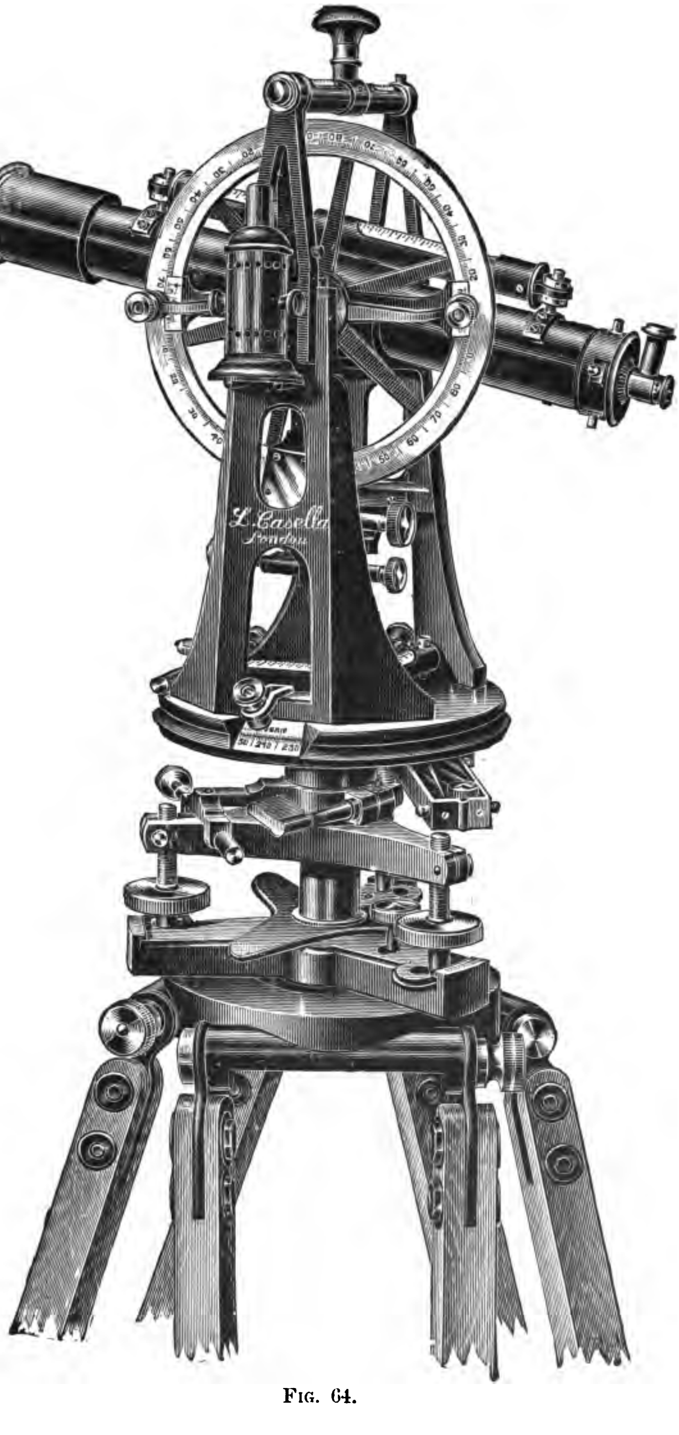


FIG. 64.

This is supplied mounted with a Hoffmann head as in Fig. 1, not as shown in illustration.

The Author does not pretend to be able to dis-

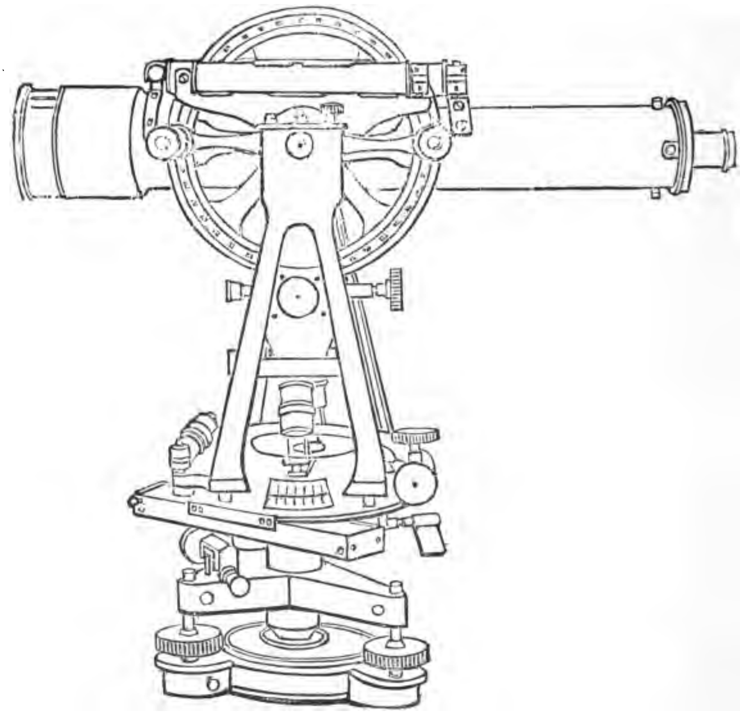


FIG. 65.

criminate between these various forms of tacheometers. As in the case of levels, choice must rest with individual predilection or caprice.

CHAPTER VIII.

ROAD TRACING.

THE Author having had considerable experience in this line, it is possible that a few practical remarks on the subject may prove of use. The alignment of a road from point to point across a hilly and unknown country is a matter in which mistakes may easily be made by inexperienced or unintelligent persons.

The first point to be considered is the ruling gradient, which of course is dependent on the traffic carried—for mules 1 in 8 to 1 in 15, for cart traffic 1 in 15 to 1 in 30; for the latter 1 in 18 or 1 in 20 are the maximum in India. In Burmah, where the loads carried are lighter, 1 in 16 can be easily negotiated. For width of road, 6 feet is sufficient for pack animals, for carts 8 feet at *least* should be cut out of the solid, leaving the spoil as extra width wherever it will lie.

In road alignments the road follows the curves of the hill-side on a rising or falling gradient, or level as the case may be, so that it is a much easier job than a railway alignment, with straight lines cutting through protuberances and curves of minimum radius. Zigzags should be avoided if it is possible to do so.

In all countries inhabited by man, footpaths invariably exist, connecting villages or crossing ranges

of hills. These will always be found to be of the greatest possible assistance—in fact indispensable—as they save much preliminary trial work. In crossing hilly country there are certain *obligatory points*, such as narrow ridges connecting two ranges of hills. To these the footpath always leads, and the road will have to cross these points as well. Hence the footpaths should always be followed; if not, the surveyor will find himself involved in hopeless difficulties necessitating a fresh alignment. In 1891 the Author had to undertake the making of an urgent military road from Wuntho to Pinlebu in Upper Burma. The distance was 44 miles across hilly and broken unsurveyed country. There was no time for any preliminary operations; the work of side cutting was started straight off with gangs of from 300 to 500 men drawn from surrounding villages by the civil authorities. It was forced labour but well paid. The Wuntho state had just been occupied by a military force and numbers of these villagers employed on the road had a few weeks before been engaged in active hostilities, if a useless waste of ammunition, followed by a "strategic movement to the rear," can thus be designated. However, they worked with a will, and the Author never had the slightest trouble in connection with them beyond having to teach them how to use the mammoties, tools which they had never seen before.

The instrument used, if such a term is applicable, consisted of two pieces of wood split off a deal box, nailed together at right angles in the shape of an inverted L. The upright leg behind being kept vertical

by the application of a plumb-bob, the horizontal arm gave a level line of sight. Two gradients—1 in 16 (the ruling gradient) and 1 in 20—were used, and the alignment was effected by fixing notched pieces of wood of the required depth on top of the level arm at its extremity. For going down hill the instrument was reversed bodily.

On commencing operations the Author was destitute of any kind of instrument, not being possessed even of a tape or two-foot rule. The depth of the cross fore-sights was obtained by the following method. A piece of paper was cut off the exact length of the horizontal arm. This was folded up till its length was reduced to $\frac{1}{16}$ and $\frac{1}{20}$ respectively. This gave the heights of the two fore-sights above the end of the level arm. With this absurdly primitive contrivance the whole 44 miles were aligned, the road tracers indented for, not arriving till after the work was completed.

The procedure was as follows. First a number of pegs were aligned by the so-called road tracer at convenient distances apart; the intervals were afterwards filled up by a native *mistri* by means of boning rods, giving level pegs in the hill-side at about every 15 feet, or even less. As soon as the pegs were in, the gang was started at work. They soon became proficient, but unfortunately the personnel was constantly changing owing to the fact, that the gangs of twenty men or so who were indented for from different villages, left the work after a week's time, their places being taken by another gang, who had to be again instructed *de novo*. This went on, till at last the whole country side had been through

the mill, and all were experienced. The great difficulty at first was to induce the men (no women were employed) to cut the earth from the hill-side and throw it at the same time, instead of the double operations of first cutting down and then shifting. No baskets were used.

As the road went along it was bridged, a separate gang of 50 to 100 men being put on this special work. Piers for bridges over wide streams were made by sinking three heavy forked branches a few feet in the sand or gravel. In the forks rested a heavy longitudinal, which carried the round beam girders, over which cross saplings were placed at right angles, on which again thick bamboo matting and two or three feet of earth or gravel were laid. To protect the piers from erosion, they were surrounded by a stout woven bamboo conical crate filled with small stones. This is a purely Burmese device, and proved very effective. These temporary bridges had not a single nail driven into them, and were provided in many cases with parapets. They lasted for about twelve or eighteen months, till the permanent wooden bridges could be put in.

Another large gang was exclusively employed in removing the immense bamboo clumps met with, and uprooting the trees which came in the road line. The latter proved such a hindrance to rapid progress, that the road was often purposely diverted to run just above the larger trees, to avoid removing them, or leaving them standing above the side cutting in a dangerous position. Some rock was met with, this was successfully blasted by the primitive method said to have been employed

by Hannibal when crossing the Alps. A large fire was lit over the rock and left for a night, next morning water was thrown over the heated mass, and a few repetitions of this simple but effective method successfully reduced the obstruction to removable fragments.

A native path led between two termini of the road, and this formed an excellent guide, the new road again and again meeting it and following it on level ground.

The whole work was completed in from three to four months, and opened for traffic as it proceeded. The Author had to do most of the work himself, having had no assistant till two-thirds was done. His sole help, the native mistri, became incapacitated through illness, and the Author had then to do all the boning rod work, as well as the clinometrical.

The native military guard were soon completely prostrated with fever, and could not accompany the moving camp, being left in villages miles away. The Author was thus left absolutely unguarded, with a treasure chest containing often several thousand rupees, alone in the jungle.

The work was so pressing that the camp was moved along almost daily to the actual road head, and it was with the utmost difficulty that the alignment could be made fast enough to keep the gangs at work without stoppage. The work continued for seven days every week without cessation till finally completed. Towards the end the Author's health broke down, but he then had the services of a keen, able, though naturally then inexperienced officer, Lieut. Adams, R.E., who hailed from Kingston College, Canada.

On at last reaching the goal, the so-called clinometer was publicly broken up amidst the shouts of the good-natured villagers who showed quite a keen interest in the work, and the Author himself was carted back to Wuntho over his road in a state bordering on collapse.

CHAPTER IX.

SURVEYING BY INTERPOLATION.

If a rough reconnaissance, including aneroid levels, is required in a country in which the leading natural features, such as isolated peaks and mountain ranges, have already been mapped, it saves an immensity of time and expense if the traverse can be surveyed and plotted by interpolation. The first reconnaissance surveys for the Mogaung extension of the Burma State Railway, and also on the Shan Hills, were largely effected by this means.

The method of procedure is this. The operator rides along the route chosen, occasionally reading the aneroid barometer and watch. The points where these levels are taken, are fixed by taking bearings to permanent peaks which are marked on the map. Each point is thus connected with three peaks, the third being necessary as a check on the accuracy of the whole. This check is very essential, as the operation is by no means so simple as it appears at first sight. The difficulty is to distinguish and recognise the salient points, as, when moving along, the same peak presents often a totally different appearance from what it did at first, and it is very possible to confound one peak with another. The difficulty is such, that it requires a very acute and

experienced observer to perform the operation with any degree of success.

The Author himself, who on first arrival in Burma was pitchforked on to the Shan Hills railway survey without any qualification for the work, attempted this feat of surveying by interpolation with disastrous results. The work would not plot anyhow, even with the help of a liberal amount of fudging. The peaks were hopelessly confused. This shows that the matter is by no means so easy, but requires a person gifted with a good eye to country and habituated to this class of work, to perform it successfully. The traverse must be taken some way off the range, as when close underneath, the peaks are quite invisible, the view being naturally cut off by the foreground.

CHAPTER X.

SURVEYING IN TROPICAL FORESTS.

THE following excerpt is taken from 'Railway Surveying in Tropical Forests,' * already alluded to on page 2—a valuable contribution, which graphically explains the method of surveying a traverse under circumstances of very great physical difficulties.

"In the following paper are described the methods adopted in surveys for locating or staking out railways with certain limits of gradients and curvature, through such unmapped countries as the British Crown Colonies of Sierra Leone, Western Gold Coast, Gold Coast and Ashanti, Lagos, British Honduras and British Guiana, where the ground is densely covered with forest and bush, through which no view can be obtained except on the roads or clearings, and then only for a few yards. In the British Honduras survey, the country was quite unknown geographically, and the only guide for the engineers to the desired terminus consisted of a series of 'truck passes,' or roads for the transport of felled timber which had been connected by clearings through the bush, until they at length formed a tortuous route to the frontier. In the Lagos colony and the countries of Egba and Yoruba, through which the railway now in course of

* Minutes of Proceedings Inst. C.E., vol. cxxxiii.

construction by the Colonial Government is to pass, only a few Europeans have been along the route of the railway, and the only map existing is a sketch made, with the help of a few rough observations of latitude and longitude, in a length of railway of 240 miles. In British Guiana the railway survey had to be taken chiefly through a country covered with dense tropical forest, and without roads or paths, and therefore without maps of any kind. The colonies of Sierra Leone and the Gold Coast were more or less in the same condition with regard to maps as the colony of Lagos.

"To obtain a good line of railway through an unknown and perhaps difficult country of great extent, four operations have to be performed. (1) A 'ride or march' over several routes, to determine the general route of the railway. (2) A 'reconnaissance survey,' to determine the approximate position of the railway on the route selected. (3) The 'location of the centre-line in detail, by obtaining a surveyed base, with cross sections of the adjoining ground, from which a section of the line can be plotted.' (4) The final 'staking out' of the centre line and preparations of a working plan and section.

"(1) *The Ride or March Over.*—The ride over is rendered necessary because a bird's-eye view of the country, owing to the density of the bush, cannot be obtained. When riding or walking over the route, the distance covered per day may be as great as that of almost any ordinary traveller, but at the same time a great deal of most useful information may be obtained, such as the times of passing all towns, villages, rivers,

small watercourses and all sources of water; particulars of large rivers and obstacles; also the nature of timber passed; cultivated products; notes on the geology of the country; a general idea of the population; number of travellers and caravans met with and the nature of their loads; healthiness of the country; and the occupation of the people. This information is booked in a 'Road Report Book,' either direct or on camping at night, and is of great value: (*a*) in choosing one out of possible routes; (*b*) in choosing camping places, &c., when the survey comes to be made along one particular route. A rough survey may be made while riding over a route if it is required, and for this the best method is perhaps that explained by Mr. F. D. Topham in a paper on 'Rapid Surveying'* This method is to take, with a prismatic compass, the deviation from magnetic north of the line from one corner of the road to the next corner, and to measure the distance by taking the time of walking or riding from corner to corner. These observations when plotted will give a very fair plan of the route traversed, and observations with an aneroid at each corner of the road will give a rough indication of the section of the road when plotted. However, in tropical countries, such as those here referred to, this method is very difficult to carry out, because the view backwards and forwards on the path is limited to a few yards, and therefore such a flying survey becomes slow and practically unfeasible. A trained observer can obtain a good idea of a route at high speed by occasional glances at the watch, aneroid and compass.

* Minutes of Proceedings Inst. C.E., vol. xcv. p. 209.

"(2) *Reconnaissance Survey.*—The general route to be adopted having been decided, the next step is to find the approximate position of the railway along the route. A base is now required from the start to the end of the line, from which to locate the railway, and the important problem to be solved in all unmapped countries is how this is to be obtained. The chief feature of the surveys now described is that the base adopted was an existing road, path, timber pass or trade route. Many engineers have cut a series of long straight lines in what was believed to be the proper direction; but the cost of such a clearing is great, because a long straight line is certain to run through hundreds of large trees which would have to be cut down,* and the time occupied is great because men can only clear at the extreme end of the line, and there is not room for more than three or four men at a time. Another serious objection to a straight line or a series of straight lines is that it may pass through obstacles and be perhaps miles from any possible route for the railway.

"After considerable experience in unmapped countries covered with dense forest, the Author has no hesitation in stating that the existing trade route, road or path, is almost invariably the best base line from which to locate the railway. After experience in tropical Africa and tropical America, he has found that existing roads are usually wonderfully direct, especially if they are much used.†

* A tree 10 feet in diameter, involving an area of 79 square feet of hard timber to be cut through in addition to buttresses, will afford four days' work for two or three men.

† In the Gold Coast (Tarkwa) survey, the trade route adopted as a base was only 2 per cent. longer than the railway surveyed.

It would seem as if through past ages the roads have gradually been improved little by little by the natives, who seem to have been constantly cutting off corners wherever they existed, until at length tropical Africa and America are traversed in all directions by footpaths which, although tortuous in detail, are as straight in their general direction as the features of the country allow. The method adopted, therefore, in the surveys for railways in the colonies of Sierra Leone, Gold Coast, Lagos and British Honduras has been to make a plan and section of the trade route or path which ran between the places desired to be touched by the railway. In this way many miles of unknown regions have been explored during 1894–97 (the total distance being 1200 miles), by various parties sent out from time to time.

"In the case of the British Guiana survey, the country to be surveyed was uninhabited and wrapped in a great tropical forest. There were no trade routes or paths of any description, so that the engineers had necessarily to cut a straight line in the direction considered desirable.

"The chains used in these surveys were steel bands $\frac{5}{8}$ inch wide, with the links, or $\frac{1}{10}$ metre, marked by brass studs. They are practically unalterable in length, usually breaking without appreciable elongation. Their great advantage in a bush country over an ordinary link-chain is that, having no projections, they do not catch in the innumerable twigs and branches. They are not very durable, and are apt to rust quickly in a damp climate, so they must be oiled every day after use. The Author, however, used only one band for

measuring 70 miles of railway in rough country, entailing many miles of cross sections cut through virgin bush.

"One engineer takes the miner's dial, while a trustworthy native or 'headman' erects a pole as far ahead as possible; the latter is attended by four or five natives with cutlasses, who cut down the bush under the headman's direction at the sides of the path until the pole can be seen from the dial. The engineer takes the back-sight of the last line on a back pole held by a native at the beginning of it, then signals the back pole to come up, then takes a fore-sight on to the front pole, superintends the natives chaining, and reads the chain at the end of the line. The miner's dial is replaced by the back pole. At the end of the line one native has, in the meantime, "blazed" a tree stump or branch as near the pole as possible, and on this the engineer or a native writes the number of the station in pencil, or more permanently if desired. The actual survey is accurately run from pole to pole, but in marking the station for future reference it is sufficient to mark the nearest tree or branch. This in a bush country is usually only a few feet from the pole. After a little practice the Author has always found the natives work well and accurately, although starting with savages without the knowledge of a word of the English language. This work can be continued all day from, say, 7 A.M. to 5 P.M. with an hour or so for the midday meal. The Author found he could survey usually 3½ miles to 4 miles a day, sometimes 6 miles in favourable country. If the path is very tortuous and the lines therefore very short, the

distance done per day is less than when the lines are longer. The number of lines in a day is fairly constant, being usually 100. In bush country 100 lines, averaging three chains each (3 miles 60 chains), is good progress, as there is a long walk back to camp, and the work has to be plotted in the evening. Moreover, the climatic conditions in all these surveys were very trying, so that the same amount of work could not be performed as would be accomplished in healthy districts.

"In one particularly rough survey in West Africa the engineer found the paths very tortuous, and having to work at very high speed was unable to clear them. He sent a man ahead a short distance, and obtained the direction of his line by judging the direction of a shout through the bush. The distance was measured by a 'perambulator,' or measuring wheel, run along the tortuous path, an allowance being made for the increase of length by the curvature of the path. This allowance with a little practice can be guessed satisfactorily.

"The section of the base is obtained by a second engineer with an ordinary dumpy level. He has two levelling staffs, a man to find the stations left by the traversing engineer, and one or two men to cut down branches in the line of sight and to cut bench marks. The level of the path is taken at every station at the mark on the tree, which is sufficiently good for obtaining a section of the road, and a bench mark is made at every tenth station for picking up levels afterwards, for levelling cross sections. All levels are checked back, and it is found usually that the levelling, including checking back, can be carried out at two-thirds the speed of

traversing, which gives the traversing engineer one day in every three working days for plotting work, writing up diaries, paysheets, reports, &c.

"Cross sections have to be cut out into large loops in the plan of the base and at all hills on the section. They have usually to be cut through intensely thick bush, involving much time and expense; so there is ample scope for discretion in order to so set out the cross sections as to avoid cutting useless lines as much as possible. Upon which side of the hill to attempt to locate the railway is always the problem to be solved, and it depends upon the engineer's ready comprehension of the lie of the country whether many useless lines are cut or not. The amount of labour involved and the time lost in cutting these cross sections may be indicated by stating that usually it takes three or four natives all day to cut or 'snick' a line about half a mile long, of width just sufficient to allow the engineer to run a chain. At a large hill on the road perhaps half a dozen cross sections are required, as much as 1 mile to 2 miles long, so the time and money wasted in cutting lines on the wrong side of the hill are considerable. If there are no paths available a long trial line is usually started each way from the top of the hill, from which it can be seen which side of the hill seems the more promising for a railway line. Cross sections are not required to be surveyed with close accuracy; speed is more important. The lines, if cut in an expeditious manner by three or four natives, are merely 'snicks' through the forest sufficiently wide to allow the chain-men to pass through. They are set out by poles from the main road, and the natives soon

learn to cut a line in the exact direction required, although they have to avoid all trees of any size. In every thick bush the Author finds it advantageous to have an extra man in each line to clean up the cut bush, as this enables the engineer to survey these cross sections more quickly and with less fatigue, than if the cut brushwood be allowed to remain and form a tangle through which it is difficult to walk. In countries such as West Africa, where labour is cheap and abundant, it should not be spared if the labour of a few natives for a day can save the engineer a few hours of work. Usually one engineer will survey and plot plan and section of about 6 miles of these cross sections in one day if the lines are cleared of tangle.

"The lines are probably surveyed the day after they are cut. The miner's dial may be used, as in the case of the base, but, as close accuracy is not required, the Author frequently uses a small pocket-compass, with sights fixed on the top of a pointed stick, which is thrust into the ground at each station. Fore-sights only are taken on these cross sections, the general direction of the line being straight. The speed with which this small compass can be worked is remarkable. The stations are marked on a 'blaze' on the nearest tree in pencil, no permanency being required. The levels are taken with a spirit-level if possible, but an aneroid is frequently employed. The difficulty of spirit-levelling through one of these narrow cross sections is much enhanced by the fact of the cross section being like a pipe. It is not only narrow, but low, and only about 6 feet of the staff can be used. An aneroid barometer

shows at its best in the case of measuring one of these cross sections. The whole line is measured in twenty minutes or half an hour, so that the atmospheric pressure has little time to vary. The engineer is obliged to return over the line, and so can check the aneroid at every station, which is marked by the numbered 'blazes' on trees. This method gave very satisfactory results with the Author, both in British Honduras and Lagos. If a cross section, owing to the formation of the ground, becomes an important one, and has branch cross sections run from it, it must be levelled over with a spirit-level. In doing this a comparison is afforded between the aneroid and the spirit-level. Time after time the Author has found his aneroid-levels correct to single feet, and rarely has found any great error; so levelling these cross sections with the aneroid seems justifiable unless the levels are wanted with greater certainty for any particular reason."

APPENDIX

TRAVERSE TABLE FOR A DISTANCE = 1.

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
0° 0′	1·0000	·0000	90° 0′	1° 0′	·9998	·0175	89° 0′
2	1·0000	·0006	58	2	·9998	·0180	58
4	1·0000	·0012	56	4	·9998	·0186	56
6	1·0000	·0017	54	6	·9998	·0192	54
8	1·0000	·0023	52	8	·9998	·0198	52
10	1·0000	·0029	50	10	·9998	·0204	50
12	1·0000	·0035	48	12	·9998	·0209	48
14	1·0000	·0041	46	14	·9998	·0215	46
16	1·0000	·0047	44	16	·9998	·0221	44
18	1·0000	·0052	42	18	·9997	·0227	42
20	1·0000	·0058	40	20	·9997	·0233	40
22	1·0000	·0064	38	22	·9997	·0239	38
24	1·0000	·0070	36	24	·9997	·0244	36
26	1·0000	·0076	34	26	·9997	·0250	34
28	1·0000	·0081	32	28	·9997	·0256	32
30	1·0000	·0087	30	30	·9997	·0262	30
32	1·0000	·0093	28	32	·9996	·0268	28
34	1·0000	·0099	26	34	·9996	·0273	26
36	·9999	·0105	24	36	·9996	·9279	24
38	·9999	·0111	22	38	·9996	·0285	22
40	·9999	·0116	20	40	·9996	·0291	20
42	·9999	·0122	18	42	·9996	·0297	18
44	·9999	·0128	16	44	·9995	·0302	16
46	·9999	·0134	14	46	·9995	·0308	14
48	·9999	·0140	12	48	·9995	·0314	12
50	·9999	·0145	10	50	·9995	·0320	10
52	·9999	·0151	8	52	·9995	·0326	8
54	·9999	·0157	6	54	·9995	·0332	6
56	·9999	·0163	4	56	·9994	·0337	4
58	·9999	·0169	2	58	·9994	·0343	2
1° 0′	·9998	·0175	89° 0′	2° 0′	·9994	·0349	88° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(continued).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
2° 0′	·9994	·0349	88° 0′	3° 0′	·9986	·0523	87° 0′
2	·9994	·0355	58	2	·9986	·0529	58
4	·9993	·0361	56	4	·9986	·0535	56
6	·9993	·0366	54	6	·9985	·0541	54
8	·9993	·0372	52	8	·9985	·0547	52
10	·9993	·0378	50	10	·9985	·0552	50
12	·9993	·0384	48	12	·9984	·0558	48
14	·9992	·0390	46	14	·9984	·0564	46
16	·9992	·0396	44	16	·9984	·0570	44
18	·9992	·0401	42	18	·9983	·0576	42
20	·9992	·0407	40	20	·9983	·0581	40
22	·9991	·0413	38	22	·9583	·0587	38
24	·9991	·0419	36	24	·9982	·0593	36
26	·9991	·0425	34	26	·9982	·0599	34
28	·9991	·0430	32	28	·9982	·0605	32
30	·9990	·0436	30	30	·9981	·0610	30
32	·9990	·0442	28	32	·9981	·0616	28
34	·9990	·0448	26	34	·9981	·0622	26
36	·9990	·0454	24	36	·9980	·0628	24
38	·9989	·0459	22	38	·9980	·0634	22
40	·9989	·0465	20	40	·9980	·0640	20
42	·9989	·0471	18	42	·9979	·0645	18
44	·9989	·0477	16	44	·9979	·0651	16
46	·9988	·0483	14	46	·9978	·0657	14
48	·9988	·0488	12	48	·9978	·0663	12
50	·9988	·0494	10	50	·9978	·0669	10
52	·9987	·0500	8	52	·9977	·0674	8
54	·9987	·0506	6	54	·9977	·0680	6
56	·9987	·0512	4	56	·9976	·0686	4
58	·9987	·0518	2	58	·9976	·0692	2
3° 0′	·9986	·0523	87° 0′	4° 0′	·9976	·0698	86° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

Traverse Table for a Distance = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
4° 0′	·9976	·0698	86° 0′	5° 0′	·9962	·0872	85° 0′
2	·9975	·0703	58	2	·9961	·0877	58
4	·9975	·0709	56	4	·9961	·0883	56
6	·9974	·0715	54	6	·9960	·0889	54
8	·9974	·0721	52	8	·9960	·0895	52
10	·9974	·0727	50	10	·9959	·09[illegible]1	50
12	·9973	·0732	48	12	·9959	·0906	48
14	·9973	·0738	46	14	·9958	·0912	46
16	·9972	·0744	44	16	·9958	·0918	44
18	·9972	·0750	42	18	·9957	·0924	42
20	·9971	·0756	40	20	·9957	·0929	40
22	·9971	·0761	38	22	·9956	·0935	38
24	·9971	·0767	36	24	·9956	·0941	36
26	·9970	·0773	34	26	·9955	·0947	34
28	·9970	·0779	32	28	·9955	·0953	32
30	·9969	·0785	30	30	·9954	·0958	30
32	·9969	·0790	28	32	·9953	·0964	28
34	·9968	·0796	26	34	·9953	·0970	26
36	·9968	·0802	24	36	·9952	·0976	24
38	·9967	·0808	22	38	·9952	·0982	22
40	·9967	·0814	20	40	·9951	·0987	20
42	·9966	·0819	18	42	·9951	·0993	18
44	·9966	·0825	16	44	·9950	·0999	16
46	·9965	·0831	14	46	·9949	·1005	14
48	·9965	·0837	12	48	·9949	·1011	12
50	·9964	·0843	10	50	·9948	·1016	10
52	·9964	·0848	8	52	·9948	·1022	8
54	·9963	·0854	6	54	·9947	·1028	6
56	·9963	·0860	4	56	·9946	·1034	4
58	·9962	·0866	2	58	·9946	·1039	2
5° 0′	·9962	·0872	85° 0′	6° 0′	·9945	·1045	84° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1 (*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
6° 0′	·9945	·1045	84° 0′	7° 0′	·9925	·1219	83° 0′
2	·9945	·1051	58	2	·9925	·1224	58
4	·9944	·1057	56	4	·9924	·1230	56
6	·9943	·1063	54	6	·9923	·1236	54
8	·9943	·1068	52	8	·9923	·1242	52
10	·9942	·1074	50	10	·9922	·1248	50
12	·9942	·1080	48	12	·9921	·1253	48
14	·9941	·1086	46	14	·9920	·1259	46
16	·9940	·1092	44	16	·9920	·1265	44
18	·9940	·1097	42	18	·9919	·1271	42
20	·9939	·1103	40	20	·9918	·1276	40
22	·9938	·1109	38	22	·9917	·1282	38
24	·9938	·1115	36	24	·9917	·1288	36
26	·9937	·1120	34	26	·9916	·1294	34
28	·9936	·1126	32	28	·9915	·1299	32
30	·9936	·1132	30	30	·9914	·1305	30
32	·9935	·1138	28	32	·9914	·1311	28
34	·9934	·1144	26	34	·9913	·1317	26
36	·9934	·1149	24	36	·9912	·1323	24
38	·9933	·1155	22	38	·9911	·1328	22
40	·9932	·1161	20	40	·9911	·1334	20
42	·9932	·1167	18	42	·9910	·1340	18
44	·9931	·1172	16	44	·9909	·1346	16
46	·9930	·1178	14	46	·9908	·1351	14
48	·9930	·1184	12	48	·9907	·1357	12
50	·9929	·1190	10	50	·9907	·1363	10
52	·9928	·1196	8	52	·9906	·1369	8
54	·9928	·1201	6	54	·9905	·1374	6
56	·9927	·1207	4	56	·9904	·1380	4
58	·9926	·1213	2	58	·9903	·1386	2
7° 0′	·9925	·1219	83° 0′	8° 0′	·9903	·1392	82° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

Traverse Table for a Distance = 1
(continued).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
8° 0′	·9903	·1392	82° 0′	9° 0′	·9877	·1564	81° 0′
2	·9902	·1397	58	2	·9876	·1570	58
4	·9901	·1403	56	4	·9875	·1576	56
6	·9900	·1409	54	6	·9874	·1582	54
8	·9899	·1415	52	8	·9873	·1587	52
10	·9899	·1421	50	10	·9872	·1593	50
12	·9898	·1426	48	12	·9871	·1599	48
14	·9897	·1432	46	14	·9870	·1605	46
16	·9896	·1438	44	16	·9869	·1610	44
18	·9895	·1444	42	18	·9869	·1616	42
20	·9894	·1449	40	20	·9868	·1622	40
22	·9894	·1455	38	22	·9867	·1628	38
24	·9893	·1461	36	24	·9866	·1633	36
26	·9892	·1467	34	26	·9865	·1639	34
28	·9891	·1472	32	28	·9864	·1645	32
30	·9890	·1478	30	30	·9863	·1650	30
32	·9889	·1484	28	32	·9862	·1656	28
34	·9888	·1490	26	34	·9861	·1662	26
36	·9888	·1495	24	36	·9860	·1668	24
38	·9887	·1501	22	38	·9859	·1673	22
40	·9886	·1507	20	40	·9858	·1679	20
42	·9885	·1513	18	42	·9857	·1685	18
44	·9884	·1518	16	44	·9856	·1691	16
46	·9883	·1524	14	46	·9855	·1696	14
48	·9882	·1530	12	48	·9854	·1702	12
50	·9881	·1536	10	50	·9853	·1708	10
52	·9880	·1541	8	52	·9852	·1714	8
54	·9880	·1547	6	54	·9851	·1719	6
56	·9879	·1553	4	56	·9850	·1725	4
58	·9878	·1559	2	58	·9849	·1731	2
9° 0′	·9877	·1564	81° 0′	10° 0′	·9848	·1736	80° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or E W.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
10° 0′	·9848	·1736	80° 0′	11° 0′	·9816	·1908	79° 0′
2	·9847	·1742	58	2	·9815	·1914	58
4	·9846	·1748	56	4	·9814	·1920	56
6	·9845	·1754	54	6	·9813	·1925	54
8	·9844	·1759	52	8	·9812	·1931	52
10	·9843	·1765	50	10	·9811	·1937	50
12	·9842	·1771	48	12	·9810	·1942	48
14	·9841	·1777	46	14	·9808	·1948	46
16	·9840	·1782	44	16	·9807	·1954	44
18	·9839	·1788	42	18	·9806	·1959	42
20	·9838	·1794	40	20	·9805	·1965	40
22	·9837	·1799	38	22	·9804	·1971	38
24	·9836	·1805	36	24	·9803	·1977	36
26	·9835	·1811	34	26	·9802	·1982	34
28	·9834	·1817	32	28	·9800	·1988	32
30	·9833	·1822	30	30	·9799	·1994	30
32	·9831	·1828	28	32	·9798	·1999	28
34	·9830	·1834	26	34	·9797	·2005	26
36	·9829	·1840	24	36	·9796	·2011	24
38	·9828	·1845	22	38	·9795	·2016	22
40	·9827	·1851	20	40	·9793	·2022	20
42	·9826	·1857	18	42	·9792	·2028	18
44	·9825	·1862	16	44	·9791	·2034	16
46	·9824	·1868	14	46	·9790	·2039	14
48	·9823	·1874	12	48	·9789	·2045	12
50	·9822	·1880	10	50	·9787	·2051	10
52	·9821	·1885	8	52	·9786	·2056	8
54	·9820	·1891	6	54	·9785	·2062	6
56	·9818	·1897	4	56	·9784	·2068	4
58	·9817	·1902	2	58	·9783	·2073	2
11° 0′	·9816	·1908	79° 0′	12° 0′	·9781	·2079	78° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

Traverse Table for a Distance = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
12° 0′	·9781	·2079	78° 0′	13° 0′	·9744	·2250	77° 0′
2	·9780	·2084	58	2	·9742	·2255	58
4	·9779	·2090	56	4	·9741	·2261	56
6	·9778	·2096	54	6	·9740	·2267	54
8	·9777	·2102	52	8	·9738	·2272	52
10	·9775	·2108	50	10	·9737	·2278	50
12	·9774	·2113	48	12	·9736	·2284	48
14	·9773	·2119	46	14	·9734	·2289	46
16	·9772	·2125	44	16	·9733	·2295	44
18	·9770	·2130	42	18	·9732	·2300	42
20	·9769	·2136	40	20	·9730	·2306	40
22	·9768	·2142	38	22	·9729	·2312	38
24	·9767	·2147	36	24	·9728	·2317	36
26	·9765	·2153	34	26	·9726	·2323	34
28	·9764	·2159	32	28	·9725	·2329	32
30	·9763	·2164	30	30	·9724	·2334	30
32	·9762	·2170	28	32	·9722	·2340	28
34	·9760	·2176	26	34	·9721	·2346	26
36	·9759	·2181	24	36	·9720	·2351	24
38	·9758	·2187	22	38	·9718	·2357	22
40	·9757	·2193	20	40	·9717	·2363	20
42	·9755	·2198	18	42	·9715	·2368	18
44	·9754	·2204	16	44	·9714	·2374	16
46	·9753	·2210	14	46	·9713	·2380	14
48	·9751	·2215	12	48	·9711	·2385	12
50	·9750	·2221	10	50	·9710	·2391	10
52	·9749	·2227	8	52	·9709	·2397	8
54	·9748	·2232	6	54	·9707	·2402	6
56	·9746	·2238	4	56	·9706	·2408	4
58	·9745	·2244	2	58	·9704	·2414	2
13° 0′	9744	·2250	77° 0′	14° 0′	·9703	·2419	76° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N.S.	Departures, or E.W.			Latitudes, or N.S.	Departures, or E.W.	
14° 0′	·9703	·2419	76° 0′	15° 0′	·9659	·2588	75° 0′
2	·9702	·2425	58	2	·9658	·2594	58
4	·9700	·2431	56	4	·9656	·2599	56
6	·9699	·2436	54	6	·9655	·2605	54
8	·9697	·2442	52	8	·9653	·2611	52
10	·9696	·2447	50	10	·9652	·2616	50
12	·9694	·2453	48	12	·9650	·2622	48
14	·9693	·2459	46	14	·9649	·2628	46
16	·9692	·2464	44	16	·9647	·2633	44
18	·9690	·2470	42	18	·9646	·2639	42
20	·9689	·2476	40	20	·9644	·2644	40
22	·9687	·2481	38	22	·9642	·2650	38
24	·9686	·2487	36	24	·9641	·2656	36
26	·9684	·2493	34	26	·9639	·2661	34
28	·9683	·2498	32	28	·9638	·2667	32
30	·9681	·2504	30	30	·9636	·2672	30
32	·9680	·2509	28	32	·9635	·2678	28
34	·9679	·2515	26	34	·9633	·2684	26
36	·9677	·2521	24	36	·9632	·2689	24
38	·9676	·2526	22	38	·9630	·2695	22
40	·9674	·2532	20	40	·9628	·2700	20
42	·9673	·2538	18	42	·9627	·2706	18
44	·9671	·2543	16	44	·9625	·2712	16
46	·9670	·2549	14	46	·9624	·2717	14
48	·9668	·2554	12	48	·9622	·2723	12
50	·9667	·2560	10	50	·9621	·2728	10
52	·9665	·2566	8	52	·9619	·2734	8
54	·9664	·2571	6	54	·9617	·2740	6
56	·9662	·2577	4	56	·9616	·2745	4
58	·9661	·2583	2	58	·9614	·2751	2
15° 0′	·9659	·2588	75° 0′	16° 0′	·9613	·2756	74° 0′
	Departures, or E.W.	Latitudes, or N.S.			Departures, or E.W.	Latitudes, or N.S.	

Traverse Table for a Distance = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
16° 0′	·9613	·2756	74° 0′	17° 0′	·9563	·2924	73° 0′
2	·9611	·2762	58	2	·9561	·2929	58
4	·9609	·2768	56	4	·9560	·2935	56
6	·9608	·2773	54	6	·9558	·2940	54
8	·9606	·2779	52	8	·9556	·2946	52
10	·9605	·2784	50	10	·9555	·2952	50
12	·9603	·2790	48	12	·9553	·2957	48
14	·9601	·2795	46	14	·9551	·2963	46
16	·9600	·2801	44	16	·9549	·2968	44
18	·9598	·2807	42	18	·9548	·2974	42
20	·9596	·2812	40	20	·9546	·2979	40
22	·9595	·2818	38	22	·9544	·2985	38
24	·9593	·2823	36	24	·9542	·2990	36
26	·9591	·2829	34	26	·9541	·2996	34
28	·9590	·2835	32	28	·9539	·3002	32
30	·9588	·2840	30	30	·9537	·3007	30
32	·9587	·2846	28	32	·9535	·3013	28
34	·9585	·2851	26	34	·9534	·3018	26
36	·9583	·2857	24	36	·9532	·3024	24
38	·9582	·2862	22	38	·9530	·3029	22
40	·9580	·2868	20	40	·9528	·3035	20
42	·9578	·2874	18	42	·9527	·3040	18
44	·9577	·2879	16	44	·9525	·3046	16
46	·9575	·2885	14	46	·9523	·3051	14
48	·9573	·2890	12	48	·9521	·3057	12
50	·9572	·2896	10	50	·9520	·3062	10
52	·9570	·2901	8	52	·9518	·3068	8
54	·9568	·2907	6	54	·9516	·3074	6
56	·9566	·2913	4	56	·9514	·3079	4
58	·9565	·2918	2	58	·9512	·3085	2
17° 0′	·9563	·2924	73° 0′	18° 0′	·9511	·3090	72° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
18° 0′	·9511	·3090	72° 0′	19° 0′	·9455	·3256	71° 0′
2	·9509	·3096	58	2	·9453	·3261	58
4	·9507	·3101	56	4	·9451	·3267	56
6	·9505	·3107	54	6	·9449	·3272	54
8	·9503	·3112	52	8	·9448	·3278	52
10	·9502	·3118	50	10	·9446	·3283	50
12	·9500	·3123	48	12	·9444	·3289	48
14	·9498	·3129	46	14	·9442	·3294	46
16	·9496	·3134	44	16	·9440	·3300	44
18	·9494	·3140	42	18	·9438	·3305	42
20	·9492	·3145	40	20	·9436	·3311	40
22	·9491	·3151	38	22	·9434	·3316	38
24	·9489	·3156	36	24	·9432	·3322	36
26	·9487	·3162	34	26	·9430	·3327	34
28	·9485	·3168	32	28	·9428	·3333	32
30	·9483	·3173	30	30	·9426	·3338	30
32	·9481	·3179	28	32	·9424	·3344	28
34	·9480	·3184	26	34	·9423	·3349	26
36	·9478	·3190	24	36	·9421	·3355	24
38	·9476	·3195	22	38	·9419	·3360	22
40	·9474	·3201	20	40	·9417	·3365	20
42	·9472	·3206	18	42	·9415	·3371	18
44	·9470	·3212	16	44	·9413	·3376	16
46	·9468	·3217	14	46	·9411	·3382	14
48	·9466	·3223	12	48	·9409	·3887	12
50	·9465	·3228	10	50	·9407	·3393	10
52	·9463	·3234	8	52	·9405	·3398	8
54	·9461	·3239	6	54	·9103	·3104	6
56	·9459	·3215	4	56	·9401	·3409	4
58	·9457	·3250	2	58	·9399	·3415	2
19° 0′	·9455	·3256	71° 0′	20° 0′	·9397	·3420	70° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
20° 0′	·9397	·3420	70° 0′	21° 0′	·9336	·3584	69° 0′
2	·9395	·3426	58	2	·9334	·3589	58
4	·9393	·3431	56	4	·9332	·3595	56
6	·9391	·3437	54	6	·9330	·3600	54
8	·9389	·3442	52	8	·9327	·3605	52
10	·9387	·3448	50	10	·9325	·3611	50
12	·9385	·3453	48	12	·9323	·3616	48
14	·9383	·3458	46	14	·9321	·3622	46
16	·9381	·3464	44	16	·9319	·3627	44
18	·9379	·3469	42	18	·9317	·3633	42
20	·9377	·3475	40	20	·9315	·3638	40
22	·9375	·3480	38	22	·9313	·3643	38
24	·9373	·3486	36	24	·9311	·3649	36
26	·9371	·3491	34	26	·9308	·3654	34
28	·9369	·3497	32	28	·9306	·3660	32
30	·9367	·3502	30	30	·9304	·3665	30
32	·9365	·3508	28	32	·9302	·3670	28
34	·9363	·3513	26	34	·9300	·3676	26
36	·9361	·3518	24	36	·9298	·3681	24
38	·9359	·3524	22	38	·9296	·3687	22
40	·9356	·3529	20	40	·9293	·3692	20
42	·9354	·3535	18	42	·9291	·3697	18
44	·9352	·3540	16	44	·9289	·3703	16
46	·9350	·3546	14	46	·9287	·3708	14
48	·9348	·3551	12	48	·9285	·3714	12
50	·9346	·3557	10	50	·9283	·3719	10
52	·9344	·3562	8	52	·9281	·3724	8
54	·9342	·3567	6	54	·9278	·3730	6
56	·9340	·3573	4	56	·9276	·3735	4
58	·9338	·3578	2	58	·9274	·3741	2
21° 0′	·9336	·3584	69° 0′	22° 0′	·9272	·3746	68° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

Traverse Table for a Distance = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
22° 0′	·9272	·3746	68° 0′	23° 0′	·9205	·3907	67° 0′
2	·9270	·3751	58	2	·9203	·3913	58
4	·9267	·3757	56	4	·9200	·3918	56
6	·9265	·3762	54	6	·9198	·3923	54
8	·9263	·3768	52	8	·9196	·3929	52
10	·9261	·3773	50	10	·9194	·3934	50
12	·9259	·3778	48	12	·9191	·3939	48
14	·9257	·3784	46	14	·9189	·3945	46
16	·9254	·3789	44	16	·9187	·3950	44
18	·9252	·3895	42	18	·9184	·3955	42
20	·9250	·3800	40	20	·9182	·3961	40
22	·9248	·3805	38	22	·9180	·3966	38
24	·9245	·3811	36	24	·9178	·3971	36
26	·9243	·3816	34	26	·9175	·3977	34
28	·9241	·3821	32	28	·9173	·3982	32
30	·9239	·3827	30	30	·9171	·3987	30
32	·9237	·3832	28	32	·9168	·3993	28
34	·9234	·3838	26	34	·9166	·3998	26
36	·9232	·3843	24	36	·9164	·4003	24
38	·9230	·3848	22	38	·9161	·4009	22
40	·9228	·3854	20	40	·9159	·4014	20
42	·9225	·3559	18	42	·9157	·4019	18
44	·9223	·3864	16	44	·9154	·4025	16
46	·9221	·3870	14	46	·9152	·4030	14
48	·9219	·3875	12	48	·9150	·4035	12
50	·9216	·3881	10	50	·9147	·4041	10
52	·9214	·3886	8	52	·9145	·4046	8
54	·9212	·3891	6	54	·9143	·4051	6
56	·9210	·3897	4	56	·9140	·4057	4
58	·9207	·3902	2	58	·9138	·4062	2
23° 0′	·9205	·3907	67° 0′	24° 0′	·9135	·4067	66° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
24° 0′	·9135	·4067	66° 0′	25° 0′	·9063	·4226	65° 0′
2	·9133	·4073	58	2	·9061	·4231	58
4	·9131	·4078	56	4	·9058	·4237	56
6	·9128	·4083	54	6	·9056	·4242	54
8	·9126	·4089	52	8	·9053	·4247	52
10	·9124	·4094	50	10	·9051	·4253	50
12	·9121	·4099	48	12	·9048	·4258	48
14	·9119	·4105	46	14	·9046	·4263	46
16	·9116	·4110	44	16	·9043	·4268	44
18	·9114	·4115	42	18	·9041	·4274	42
20	·9112	·4120	40	20	·9038	·4279	40
22	·9109	·4126	38	22	·9036	·4284	38
24	·9107	·4131	36	24	·9033	·4289	36
26	·9104	·4136	34	26	·9031	·4295	34
28	·9102	·4142	32	28	·9028	·4300	32
30	·9100	·4147	30	30	·9026	·4305	30
32	·9097	·4152	28	32	·9023	·4310	28
34	·9095	·4158	26	34	·9021	·4316	26
36	·9092	·4163	24	36	·9018	·4321	24
38	·9090	·4168	22	38	·9016	·4326	22
40	·9088	·4173	20	40	·9013	·4331	20
42	·9085	·4179	18	42	·9011	·4337	18
44	·9083	·4184	16	44	·9008	·4342	16
46	·9080	·4189	14	46	·9006	·4347	14
48	·9078	·4195	12	48	·9003	·4352	12
50	·9075	·4200	10	50	·9001	·4358	10
52	·9073	·4205	8	52	·8998	·4363	8
54	·9070	·4210	6	54	·8996	·4368	6
56	·9068	·4216	4	56	·8993	·4373	4
58	·9066	·4221	2	58	·8990	·4378	2
25° 0′	·9063	·4226	65° 0′	26° 0′	·8988	·4384	64° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departrues, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
26° 0′	·8988	·4384	64° 0′	27° 0′	·8910	·4540	63° 0′
2	·8985	·4389	58	2	·8907	·4545	58
4	·8983	·4394	56	4	·8905	·4550	56
6	·8980	·4399	54	6	·8902	·4555	54
8	·8978	·4405	52	8	·8899	·4561	52
10	·8975	·4410	50	10	·8897	·4566	50
12	·8973	·4415	48	12	·8894	·4571	48
14	·8970	·4420	46	14	·8892	·4576	46
16	·8967	·4425	44	16	·8889	·4581	44
18	·8965	·4431	42	18	·8886	·4586	42
20	·8962	·4436	40	20	·8884	·4592	40
22	·8960	·4441	38	22	·8881	·4597	38
24	·8957	·4446	36	24	·8878	·4602	36
26	·8955	·4452	34	26	·8875	·4607	34
28	·8952	·4457	32	28	·8873	·4612	32
30	·8949	·4462	30	30	·8870	·4617	30
32	·8947	·4467	28	32	·8867	·4623	28
34	·8944	·4472	26	34	·8865	·4628	26
36	·8942	·4478	24	36	·8862	·4633	24
38	·8939	·4483	22	38	·8859	·4638	22
40	·8936	·4488	20	40	·8857	·4643	20
42	·8934	·4493	18	42	·8854	·4648	18
44	·8931	·4498	16	44	·8851	·4654	16
46	·8928	·4504	14	46	·8849	·4659	14
48	·8926	·4509	12	48	·8846	·4664	12
50	·8923	·4514	10	50	·8843	·4669	10
52	·8921	·4519	8	52	·8840	·4674	8
54	·8918	·4524	6	54	·8838	·4679	6
56	·8915	·4530	4	56	·8835	·4684	4
58	·8913	·4535	2	58	·8832	·4690	2
27° 0′	·8910	·4540	63° 0′	28° 0′	·8829	·4695	62° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

Traverse Table for a Distance = 1
(continued).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
28° 0′	·8829	·4695	62° 0′	29° 0′	·8746	·4848	61° 0′
2	·8827	·4700	58	2	·8743	·4853	58
4	·8824	·4705	56	4	·8741	·4858	56
6	·8821	·4710	54	6	·8738	·4863	54
8	·8819	·4715	52	8	·8735	·4868	52
10	·8816	·4720	50	10	·8732	·4874	50
12	·8813	·4726	48	12	·8729	·4879	48
14	·8810	·4731	46	14	·8726	·4884	46
16	·8808	·4736	44	16	·8724	·4889	44
18	·8805	·4741	42	18	·8721	·4894	42
20	·8802	·4746	40	20	·8718	·4899	40
22	·8799	·4751	38	22	·8715	·4904	38
24	·8796	·4756	36	24	·8712	·4909	36
26	·8794	·4761	34	26	·8709	·4914	34
28	·8791	·4766	32	28	·8706	·4919	32
30	·8788	·4772	30	30	·8704	·4924	30
32	·8785	·4777	28	32	·8701	·4929	28
34	·8783	·4782	26	34	·8698	·4934	26
36	·8780	·4787	24	36	·8695	·4939	24
38	·8777	·4792	22	38	·8692	·4944	22
40	·8774	·4797	20	40	·8689	·4950	20
42	·8771	·4802	18	42	·8686	·4955	18
44	·8769	·4807	16	44	·8683	·4960	16
46	·8766	·4812	14	46	·8681	·4965	14
48	·8763	·4818	12	48	·8678	·4970	12
50	·8760	·4823	10	50	·8675	·4975	10
52	·8757	·4828	8	52	·8672	·4980	8
54	·8755	·4833	6	54	·8669	·4985	6
56	·8752	·4838	4	56	·8666	·4990	4
58	·8749	·4843	2	58	·8663	·4995	2
29° 0′	·8746	·4848	61° 0′	30° 0′	·8660	·5000	60° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
30° 0′	·8660	·5000	60° 0′	31° 0′	·8572	·5150	59° 0′
2	·8657	·5005	58	2	·8569	·5155	58
4	·8654	·5010	56	4	·8566	·5160	56
6	·8652	·5015	54	6	·8563	·5165	54
8	·8649	·5020	52	8	·8560	·5170	52
10	·8646	·5025	50	10	·8557	·5175	50
12	·8643	·5030	48	12	·8554	·5180	48
14	·8640	·5035	46	14	·8551	·5185	46
16	·8637	·5040	44	16	·8548	·5190	44
18	·8634	·5045	42	18	·8545	·5195	42
20	·8631	·5050	40	20	·8542	·5200	40
22	·8628	·5055	38	22	·8539	·5205	38
24	·8625	·5060	36	24	·8536	·5210	36
26	·8622	·5065	34	26	·8532	·5215	34
28	·8619	·5070	32	28	·8529	·5220	32
30	·8616	·5075	30	30	·8526	·5225	30
32	·8613	·5080	28	32	·8523	·5230	28
34	·8610	·5085	26	34	·8520	·5235	26
36	·8607	·5090	24	36	·8517	·5240	24
38	·8604	·5095	22	38	·8514	·5245	22
40	·8601	·5100	20	40	·8511	·5250	20
42	·8599	·5105	18	42	·8508	·5255	18
44	·8596	·5110	16	44	·8505	·5260	16
46	·8593	·5115	14	46	·8502	·5265	14
48	·8590	·5120	12	48	·8499	·5270	12
50	·8587	·5125	10	50	·8496	·5275	10
52	·8584	·5130	8	52	·8493	·5279	8
54	·8581	·5135	6	54	·8490	·5284	6
56	·8578	·5140	4	56	·8487	·5289	4
58	·8575	·5145	2	58	·8484	·5294	2
31° 0′	·8572	·5150	59° 0′	32° 0′	·8480	·5299	58° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
32° 0′	·8480	·5299	58° 0′	33° 0′	·8387	·5446	57° 0′
2	·8477	·5304	58	2	·8384	·5451	58
4	·8474	·5309	56	4	·8380	·5456	56
6	·8471	·5314	54	6	·8377	·5461	54
8	·8468	·5319	52	8	·8374	·5466	52
10	·8465	·5324	50	10	·8371	·5471	50
12	·8462	·5329	48	12	·8368	·5476	48
14	·8459	·5334	46	14	·8364	·5480	46
16	·8456	·5339	44	16	·8361	·5485	44
18	·8453	·5344	42	18	·8358	·5490	42
20	·8450	·5348	40	20	·8355	·5495	40
22	·8446	·5353	38	22	·8352	·5500	38
24	·8443	·5358	36	24	·8348	·5505	36
26	·8440	·5363	34	26	·8345	·5510	34
28	·8437	·5368	32	28	·8342	·5515	32
30	·8434	·5373	30	30	·8339	·5519	30
32	·8431	·5378	28	32	·8336	·5524	28
34	·8428	·5383	26	34	·8332	·5529	26
36	·8425	·5388	24	36	·8329	·5534	24
38	·8421	·5393	22	38	·8326	·5539	22
40	·8418	·5398	20	40	·8323	·5544	20
42	·8415	·5402	18	42	·8320	·5548	18
44	·8412	·5407	16	44	·8316	·5553	16
46	·8409	·5412	14	46	·8313	·5558	14
48	·8406	·5417	12	48	·8310	·5563	12
50	·8403	·5422	10	50	·8307	·5568	10
52	·8399	·5427	8	52	·8303	·5573	8
54	·8396	·5432	6	54	·8300	·5577	6
56	·8393	·5437	4	56	·8297	·5582	4
58	·8390	·5442	2	58	·8294	·5587	2
33° 0′	·8387	·5446	57° 0′	34° 0′	·8290	·5592	56° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
34° 0′	·8290	·5592	56° 0′	35° 0′	·8192	·5736	55° 0′
2	·8287	·5597	58	2	·8188	·5741	58
4	·8284	·5602	56	4	·8185	·5745	56
6	·8281	·5606	54	6	·8181	·5750	54
8	·8277	·5611	52	8	·8178	·5755	52
10	·8274	·5616	50	10	·8175	·5760	50
12	·8271	·5621	48	12	·8171	·5764	48
14	·8268	·5626	46	14	·8168	·5769	46
16	·8264	·5630	44	16	·8165	·5774	44
18	·8261	·5635	42	18	·8161	·5779	42
20	·8258	·5640	40	20	·8158	·5783	40
22	·8254	·5645	38	22	·8155	·5788	38
24	·8251	·5650	36	24	·8151	·5793	36
26	·8248	·5654	34	26	·8148	·5798	34
28	·8245	·5659	32	28	·8145	·5802	32
30	·8241	·5664	30	30	·8141	·5807	30
32	·8238	·5669	28	32	·8138	·5812	28
34	·8235	·5674	26	34	·8134	·5816	26
36	·8231	·5678	24	36	·8131	·5821	24
38	·8228	·5683	22	38	·8128	·5826	22
40	·8225	·5688	20	40	·8124	·5831	20
42	·8221	·5693	18	42	·8121	·5835	18
44	·8218	·5698	16	44	·8117	·5840	16
46	·8215	·5702	14	46	·8114	·5845	14
48	·8211	·5707	12	48	·8111	·5850	12
50	·8208	·5712	10	50	·8107	·5854	10
52	·8205	·5717	8	52	·8104	·5859	8
54	·8202	·5721	6	54	·8100	·5864	6
56	·8198	·5726	4	56	·8097	·5868	4
58	·8195	·5731	2	58	·8094	·5873	2
35° 0′	·8192	·5736	55° 0′	36° 0′	·8090	·5878	54° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
36° 0′	·8090	·5878	54° 0′	37° 0′	·7986	·6018	53° 0′
2	·8087	·5883	58	2	·7983	·6023	58
4	·8083	·5887	56	4	·7979	·6027	56
6	·8080	·5892	54	6	·7976	·6032	54
8	·8076	·5897	52	8	·7972	·6037	52
10	·8073	·5901	50	10	·7969	·6041	50
12	·8070	·5906	48	12	·7965	·6046	48
14	·8066	·5911	46	14	·7962	·6051	46
16	·8063	·5915	44	16	·7958	·6055	44
18	·8059	·5920	42	18	·7955	·6060	42
20	·8056	·5925	40	20	·7951	·6065	40
22	·8052	·5930	38	22	·7948	·6069	38
24	·8049	·5934	36	24	·7944	·6074	36
26	·8045	·5939	34	26	·7941	·6078	34
28	·8042	·5944	32	28	·7937	·6083	32
30	·8039	·5948	30	30	·7934	·6088	30
32	·8035	·5953	28	32	·7930	·6092	28
34	·8032	·5958	26	34	·7926	·6097	26
36	·8028	·5962	24	36	·7923	·6101	24
38	·8025	·5967	22	38	·7919	·6106	22
40	·8021	·5972	20	40	·7916	·6111	20
42	·8018	·5976	18	42	·7912	·6115	18
44	·8014	·5981	16	44	·7909	·6120	16
46	·8011	·5986	14	46	·7905	·6124	14
48	·8007	·5990	12	48	·7902	·6129	12
50	·8004	·5995	10	50	·7898	·6134	10
52	·8000	·6000	8	52	·7894	·6138	8
54	·7997	·6004	6	54	·7891	·6143	6
56	·7993	·6009	4	56	·7887	·6147	4
58	·7990	·6014	2	58	·7884	·6152	2
37° 0′	·7986	·6018	53° 0′	38° 0′	·7880	·6157	52° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
38° 0′	·7880	·6157	52° 0′	39° 0′	·7771	·6293	51° 0′
2	·7877	·6161	58	2	·7768	·6298	58
4	·7873	·6166	56	4	·7764	·6302	56
6	·7869	·6170	54	6	·7760	·6307	54
8	·7866	·6175	52	8	·7757	·6311	52
10	·7862	·6180	50	10	·7753	·6316	50
12	·7859	·6184	48	12	·7749	·6320	48
14	·7855	·6189	46	14	·7746	·6325	46
16	·7851	·6193	44	16	·7742	·6329	44
18	·7848	·6198	42	18	·7738	·6334	42
20	·7844	·6202	40	20	·7735	·6338	40
22	·7841	·6207	38	22	·7731	·6343	38
24	·7837	·6211	36	24	·7727	·6347	36
26	·7833	·6216	34	26	·7724	·6352	34
28	·7830	·6221	32	28	·7720	·6356	32
30	·7826	·6225	30	30	·7716	·6361	30
32	·7822	·6230	28	32	·7713	·6365	28
34	·7819	·6234	26	34	·7709	·6370	26
36	·7815	·6239	24	36	·7705	·6374	24
38	·7812	·6243	22	38	·7701	·6379	22
40	·7808	·6248	20	40	·7698	·6383	20
42	·7804	·6252	18	42	·7694	·6388	18
44	·7801	·6257	16	44	·7690	·6392	16
46	·7797	·6262	14	46	·7687	·6397	14
48	·7793	·6266	12	48	·7683	·6401	12
50	·7790	·6271	10	50	·7679	·6406	10
52	·7786	·6275	8	52	·7675	·6410	8
54	·7782	·6280	6	54	·7672	·6414	6
56	·7779	·6284	4	56	·7668	·6419	4
58	·7775	·6289	2	58	·7664	·6423	2
39° 0′	·7771	·6293	51° 0′	40° 0′	·7660	·6428	50° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or F. S.	

Traverse Table for a Distance = 1
(continued).

	Latitudes, or N. S.	Departures, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
40° 0′	·7660	·6428	50° 0′	41° 0′	·7547	·6561	49° 0′
2	·7657	·6432	58	2	·7543	·6565	58
4	·7653	·6437	56	4	·7539	·6569	56
6	·7649	·6441	54	6	·7536	·6574	54
8	·7645	·6446	52	8	·7532	·6578	52
10	·7642	·6450	50	10	·7528	·6583	50
12	·7638	·6455	48	12	·7524	·6587	48
14	·7634	·6459	46	14	·7520	·6591	46
16	·7630	·6463	44	16	·7516	·6596	44
18	·7627	·6468	42	18	·7513	·6600	42
20	·7623	·6472	40	20	·7509	·6604	40
22	·7619	·6477	38	22	·7505	·6609	38
24	·7615	·6481	36	24	·7501	·6613	36
26	·7612	·6486	34	26	·7497	·6617	34
28	·7608	·6490	32	28	·7493	·6622	32
30	·7604	·6494	30	30	·7490	·6626	30
32	·7600	·6499	28	32	·7486	·6631	28
34	·7596	·6503	26	34	·7482	·6635	26
36	·7593	·6508	24	36	·7478	·6639	24
38	·7589	·6512	22	38	·7474	·6644	22
40	·7585	·6517	20	40	·7470	·6648	20
42	·7581	·6521	18	42	·7466	·6652	18
44	·7578	·6525	16	44	·7463	·6657	16
46	·7574	·6530	14	46	·7459	·6661	14
48	·7570	·6534	12	48	·7455	·6665	12
50	·7566	·6539	10	50	·7451	·6670	10
52	·7562	·6543	8	52	·7447	·6674	8
54	·7559	·6547	6	54	·7443	·6678	6
56	·7555	·6552	4	56	·7439	·6683	4
58	·7551	·6556	2	58	·7435	·6687	2
41° 0′	·7547	·6561	49° 0′	42° 0′	·7431	·6691	48° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N.S.	Departures, or E.W.			Latitudes, or N.S.	Departures, or E.W.	
42° 0′	·7431	·6691	48° 0′	43° 0′	·7314	·6820	47° 0′
2	·7428	·6696	58	2	·7310	·6824	58
4	·7424	·6700	56	4	·7306	·6828	56
6	·7420	·6704	54	6	·7302	·6833	54
8	·7416	·6709	52	8	·7298	·6837	52
10	·7412	·6713	50	10	·7294	·6841	50
12	·7408	·6717	48	12	·7290	·6845	48
14	·7404	·6722	46	14	·7286	·6850	46
16	·7400	·6726	44	16	·7282	·6854	44
18	·7396	·6730	42	18	·7278	·6858	42
20	·7392	·6734	40	20	·7274	·6862	40
22	·7388	·6739	38	22	·7270	·6867	38
24	·7385	·6743	36	24	·7266	·6871	36
26	·7381	·6747	34	26	·7262	·6875	34
28	·7377	·6752	32	28	·7258	·6879	32
30	·7373	·6756	30	30	·7254	·6884	30
32	·7369	·6760	28	32	·7250	·6888	28
34	·7365	·6764	26	34	·7246	·6892	26
36	·7361	·6769	24	36	·7242	·6896	24
38	·7357	·6773	22	38	·7238	·6900	22
40	·7353	·6777	20	40	·7234	·6905	20
42	·7349	·6782	18	42	·7230	·6909	18
44	·7345	·6786	16	44	·7226	·6913	16
46	·7341	·6790	14	46	·7222	·6917	14
48	·7337	·6794	12	48	·7218	·6921	12
50	·7333	·6799	10	50	·7214	·6926	10
52	·7329	·6803	8	52	·7210	·6930	8
54	·7325	·6807	6	54	·7206	·6934	6
56	·7321	·6811	4	56	·7201	·6938	4
58	·7318	·6816	2	58	·7197	·6942	2
43° 0′	·7314	·6820	47° 0′	44° 0′	·7193	·6947	46° 0′
	Departures, or E.W.	Latitudes, or N.S.			Departures, or E.W.	Latitudes, or N.S.	

TRAVERSE TABLE FOR A DISTANCE = 1
(*continued*).

	Latitudes, or N. S.	Departure, or E. W.			Latitudes, or N. S.	Departures, or E. W.	
44° 0′	·7193	·6947	46° 0′	44° 30′	·7133	·7009	46° 30′
2	·7189	·6951	58	32	·7128	·7013	28
4	·7185	·6955	56	34	·7124	·7017	26
6	·7181	·6959	54	36	·7120	·7021	24
8	·7177	·6963	52	38	·7116	·7026	22
10	·7173	·6967	50	40	·7112	·7030	20
12	·7169	·6972	48				
14	·7165	·6976	46	42	·7108	·7034	18
16	·7161	·6980	44	44	·7104	·7038	16
18	·7157	·6984	42	46	·7100	·7042	14
20	·7153	·6988	40	48	·7096	·7046	12
				50	·7092	·7050	10
22	·7149	·6992	38	52	·7088	·7055	8
24	·7145	·6997	36	54	·7083	·7059	6
26	·7141	·7001	34	56	·7079	·7063	4
28	·7137	·7005	32	58	·7075	·7067	2
44° 30′	·7133	·7009	46° 30′	45° 0′	·7071	·7071	45° 0′
	Departures, or E. W.	Latitudes, or N. S.			Departures, or E. W.	Latitudes, or N. S.	

CHORDS TO A RADIUS 1.

M.	0°	1°	2°	3°	4°	5°
0′	·0000	·0175	·0349	·0524	·0698	·0872
2	·0006	·0180	·0355	·0529	·0704	·0878
4	·0012	·0186	·0361	·0535	·0710	·0884
6	·0017	·0192	·0366	·0541	·0715	·0890
8	·0023	·0198	·0372	·0547	·0721	·0896
10	·0029	·0204	·0378	·0553	·0727	·0901
12	·0035	·0209	·0384	·0558	·0733	·0907
14	·0041	·0215	·0390	·0564	·0739	·0913
16	·0047	·0221	·0396	·0570	·0745	·0919
18	·0052	·0227	·0401	·0576	·0750	·0925
20	·0058	·0233	·0407	·0582	·0756	·0931
22	·0064	·0239	·0413	·0588	·0762	·0936
24	·0070	·0244	·0419	·0593	·0768	·0942
26	·0076	·0250	·0425	·0599	·0774	·0948
28	·0081	·0256	·0430	·0605	·0779	·0954
30	·0087	·0262	·0436	·0611	·0785	·0960
32	·0093	·0268	·0442	·0617	·0791	·0965
34	·0099	·0273	·0448	·0622	·0797	·0971
36	·0105	·0279	·0454	·0628	·0803	·0977
38	·0111	·0285	·0460	·0634	·0808	·0983
40	·0116	·0291	·0465	.0640	·0814	·0989
42	·0122	·0297	·0471	·0646	·0820	·0994
44	·0128	·0303	·0477	·0651	·0826	·1000
46	·0134	·0308	·0483	·0657	·0832	·1006
48	·0140	·0314	·0489	·0663	·0838	·1012
50	.0145	·0320	·0494	·0669	·0843	·1018
52	·0151	·0326	·0500	·0675	·0849	·1023
54	·0157	·0332	·0506	·0681	·0855	·1029
56	·0163	·0337	·0512	·0686	·0861	·1035
58	·0169	·0343	·0518	·0692	·0867	·1041
60	·0175	·0349	·0524	·0698	·0872	·1047

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	6°	7°	8°	9°	10°
0′	·1047	·1221	·1395	·1569	·1743
2	·1053	·1227	·1401	·1575	·1749
4	·1058	·1233	·1407	·1581	·1755
6	·1064	·1238	·1413	·1587	·1761
8	·1070	·1244	·1418	·1592	·1766
10	·1076	·1250	·1424	·1598	·1772
12	·1082	·1256	·1430	·1604	·1778
14	·1087	·1262	·1436	·1610	·1784
16	·1093	·1267	·1442	·1616	·1789
18	·1099	·1273	·1447	·1621	·1795
20	·1105	·1279	·1453	·1627	·1801
22	·1111	·1285	·1459	·1633	·1807
24	·1116	·1291	·1465	·1639	·1813
26	·1122	·1296	·1471	·1645	·1818
28	·1128	·1302	·1476	·1650	·1824
30	·1134	.1308	·1482	·1656	·1830
32	·1140	·1314	·1488	·1662	·1836
34	·1145	·1320	·1494	·1668	·1842
36	·1151	·1325	·1500	·1674	·1847
38	·1157	·1331	·1505	·1679	·1853
40	·1163	·1337	·1511	·1685	·1859
42	·1169	·1343	·1517	·1691	·1865
44	·1175	·1349	·1523	·1697	·1871
46	·1180	·1355	·1529	·1703	·1876
48	·1186	·1360	·1534	·1708	·1882
50	·1192	·1366	·1540	·1714	·1888
52	·1198	·1372	·1546	·1720	·1894
54	·1204	·1378	·1552	·1726	·1900
56	·1209	·1384	·1558	·1732	·1905
58	·1215	·1389	·1563	·1737	·1911
60	·1221	·1395	·1569	·1743	·1917

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING
(*continued*).

M.	11°	12°	13°	14°	15°
0′	·1917	·2091	·2264	·2437	·2611
2	·1923	·2096	·2270	·2443	·2616
4	·1928	·2102	·2276	·2449	·2622
6	·1934	·2108	·2281	·2455	·2628
8	·1940	·2114	·2287	·2460	·2634
10	·1946	·2119	·2293	·2466	·2639
12	·1952	·2125	·2299	·2472	·2645
14	·1957	·2131	·2305	·2478	·2651
16	·1963	·2137	·2310	·2484	·2657
18	·1969	·2143	·2316	·2489	·2662
20	·1975	·2148	·2322	·2495	·2668
22	·1981	·2154	·2328	·2501	·2674
24	·1986	·2160	·2333	·2507	·2680
26	·1992	·2166	·2339	·2512	·2685
28	·1998	·2172	·2345	·2518	·2691
30	·2004	·2177	·2351	·2524	·2697
32	·2010	·2183	·2357	·2530	·2703
34	·2015	·2189	·2362	·2536	·2709
36	·2021	·2195	·2368	·2541	·2714
38	·2027	·2200	·2374	·2547	·2720
40	·2033	·2206	·2380	·2553	·2726
42	·2038	·2212	·2385	·2559	·2732
44	·2044	·2218	·2391	·2564	·2737
46	·2050	·2224	·2397	·2570	·2743
48	·2056	·2229	·2403	·2576	·2749
50	·2062	·2235	·2409	·2582	·2755
52	·2067	·2241	·2414	·2587	·2760
54	·2073	·2247	·2420	·2593	·2766
56	·2079	·2253	·2426	·2599	·2772
58	·2085	·2258	·2432	·2605	·2778
60	·2091	·2264	·2437	·2611	·2783

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	16°	17°	18°	19°	20°
0′	·2783	·2956	·3129	·3301	·3473
2	·2789	·2962	·3134	·3307	·3479
4	·2795	·2968	·3140	·3312	·3484
6	·2801	·2973	·3146	·3318	·3490
8	·2807	·2979	·3152	·3324	·3496
10	·2812	·2985	·3157	·3330	·3502
12	·2818	·2991	·3163	·3335	·3507
14	·2824	·2996	·3169	·3341	·3513
16	·2830	·3002	·3175	·3347	·3519
18	·2835	·3008	·3180	·3353	·3525
20	·2841	·3014	·3186	·3358	·3530
22	·2847	·3019	·3192	·3364	·3536
24	·2853	·3025	·3198	·3370	·3542
26	·2858	·3031	·3203	·3376	·3547
28	·2864	·3037	·3209	·3381	·3553
30	·2870	·3042	·3215	·3387	·3559
32	·2876	·3048	·3221	·3393	·3565
34	·2881	·3054	·3226	·3398	·3570
36	·2887	·3060	·3232	·3404	·3576
38	·2893	·3065	·3238	·3410	·3582
40	·2899	·3071	·3244	·3416	·3587
42	·2904	·3077	·3249	·3421	·3593
44	·2910	·3083	·3255	·3427	·3599
46	·2916	·3088	·3261	·3433	·3605
48	·2922	·3094	·3267	·3439	·3610
50	·2927	·3100	·3272	·3444	·3616
52	·2933	·3106	·8278	·3450	·3622
54	·2939	·3111	·3284	·3456	·3628
56	·2945	·3117	·3289	·3462	·3633
58	·2950	·3123	·3295	·3467	·3639
60	·2956	·3129	·3301	.3473	·3645

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	21°	22°	23°	24°	25°
0′	·3645	·3816	·3987	·4158	·4329
2	·3650	·3822	·3993	·4164	·4334
4	·3656	·3828	·3999	·4170	·4340
6	·3662	·3833	·4004	·4175	·4346
8	·3668	·3839	·4010	·4181	·4352
10	·3673	·3845	·4006	·4187	·4357
12	·3679	·3850	·4022	·4192	·4363
14	·3685	·3856	·4027	·4198	·4369
16	·3690	·3862	·4033	·4204	·4374
18	·3696	·3868	·4039	·4209	·4380
20	·3702	·3873	·4044	·4215	·4386
22	·3708	·3879	·4050	·4221	·4391
24	·3713	·3885	·4056	·4226	·4397
26	·3719	·3890	·4061	·4232	·4403
28	·3725	·3896	·4067	·4238	·4408
30	·3730	·3902	·4073	·4244	·4414
32	·3736	·3908	·4079	·4249	·4420
34	·3742	·3913	·4084	·4255	·4425
36	·3748	·3919	·4090	·4261	·4431
38	·3753	·3925	·4096	·4266	·4437
40	·3759	·3930	·4101	·4272	·4442
42	·3765	·3936	·4107	·4278	·4448
44	·3770	·3942	·4113	·4283	·4454
46	·3776	·3947	·4118	·4289	·4459
48	·3782	·3953	·4124	·4295	·4465
50	·3788	·3959	·4130	·4300	·4471
52	·3793	·3965	·4135	·4306	·4476
54	·3799	·3970	·4141	·4312	·4482
56	·3805	·3976	·4147	·4317	·4488
58	·3810	·3982	·4153	·4323	·4493
60	·3816	·3987	·4158	·4329	·4499

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	26°	27°	28°	29°	30°
0′	·4499	·4669	·4838	·5008	·5176
2	·4505	·4675	·4844	·5013	·5182
4	·4510	·4680	·4850	·5019	·5188
6	·4516	·4686	·4855	·5024	·5193
8	·4522	·4692	·4861	·5030	·5199
10	·4527	·4697	·4867	·5036	·5204
12	·4533	·4703	·4872	·5041	·5210
14	·4539	·4708	·4378	·5047	·5216
16	·4544	·4714	·4884	·5053	·5221
18	·4550	·4720	·4889	·5058	·5227
20	·4556	·4725	·4895	·5064	·5233
22	·4561	·4731	·4901	·5070	·5238
24	·4567	·4737	·4906	·5075	·5244
26	·4573	·4742	·4912	·5081	·5249
28	·4578	·4748	·4917	·5086	·5255
30	·4584	·4754	·4923	·5092	·5261
32	·4590	·4759	·4929	·5098	·5266
34	·4595	·4765	·4934	·5103	·5272
36	·4601	·4771	·4940	·5109	·5277
38	·4607	·4776	·4946	·5115	·5283
40	·4612	·4782	·4951	·5120	·5289
42	·4618	·4788	·4957	·5126	·5294
44	·4624	·4793	·4963	·5131	·5300
46	·4629	·4799	·4968	·5137	·5306
48	·4635	·4805	·4974	·5143	·5311
50	·4641	·4810	·4979	·5148	·5317
52	·4646	·4816	.4985	·5154	·5322
54	·4652	·4822	·4991	·5160	·5328
56	·4658	·4827	·4996	·5165	·5334
58	·4663	·4833	·5002	·5171	·5339
60	·4669	·4838	·5008	·5176	·5345

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	31°	32°	33°	34°	35°
0′	·5345	·5513	·5680	·5847	·6014
2	·5350	·5518	·5686	·5853	·6020
4	·5356	·5524	·5691	·5859	·6025
6	·5362	·5530	·5697	·5864	·6031
8	·5367	·5535	·5703	·5870	·6036
10	·5373	·5541	·5708	·5875	·6042
12	·5378	·5546	·5714	·5881	·6047
14	·5384	·5552	·5719	5886	·6053
16	·5390	·5557	·5725	·5892	·6058
18	·5395	·5563	·5730	·5897	·6064
20	·5401	·5569	·5736	·5903	·6070
22	·5406	·5574	·5742	·5909	·6075
24	·5412	·5580	·5747	·5914	·6081
26	·5418	·5585	·5753	·5920	·6086
28	·5423	·5591	·5758	·5925	·6092
30	·5429	·5597	·5764	·5931	·6097
32	·5434	·5602	·5769	·5936	·6103
34	·5440	·5608	·5775	·5942	·6108
36	·5446	·5613	·5781	·5947	·6114
38	·5451	·5619	·5786	·5953	·6119
40	·5457	·5625	·5792	·5959	·6125
42	·5462	·5630	·5797	·5964	·6130
44	·5468	·5636	·5803	·5970	·6136
46	·5474	·5641	·5808	·5975	·6142
48	·5479	·5647	·5814	·5981	·6147
50	·5485	·5652	·5820	·5986	·6153
52	·5490	·5658	·5825	·5992	·6158
54	·5496	·5664	·5831	·5997	·6164
56	·5502	·5669	·5836	·6003	·6169
58	·5507	·5675	·5842	·6009	·6175
60	·5513	·5680	·5847	·6014	·6180

Table of Chords, in Parts of a Radius 1; for Protracting (*continued*).

M.	36°	37°	38°	39°	40°
0′	·6180	·6346	·6511	·6676	·6840
2	·6186	·6352	·6517	·6682	·6846
4	·6191	·6357	·6522	·6687	·6851
6	·6197	·6363	·6528	·6693	·6857
8	·6202	·6368	·6533	·6698	·6862
10	·6208	·6374	·6539	·6704	·6868
12	·6214	·6379	·6544	·6709	·6873
14	·6219	·6385	·6550	·6715	·6879
16	·6225	·6390	·6555	·6720	·6884
18	·6230	·6396	·6561	·6725	·6890
20	·6236	·6401	·6566	·6731	·6895
22	·6241	·6407	·6572	·6736	·6901
24	·6247	·6412	·6577	·6742	·6906
26	·6252	·6418	·6583	·6747	·6911
28	·6258	·6423	·6588	·6753	·6917
30	·6263	·6429	·6594	·6758	·6922
32	·6269	·6434	·6599	·6764	·6928
34	·6274	·6440	·6605	·6769	·6933
36	·6280	·6445	·6610	·6775	·6939
38	·6285	·6451	·6616	·6780	·6944
40	·6291	·6456	·6621	·6786	·6950
42	·6296	·6462	·6627	·6791	·6955
44	·6302	·6467	·6632	·6797	·6961
46	·6307	·6473	·6638	·6802	·6966
48	·6313	·6478	·6643	·6808	·6971
50	·6318	·6484	·6649	·6813	·6977
52	·6324	·6489	·6654	·6819	·6982
54	·6330	·6495	·6660	·6824	·6988
56	·6335	·6500	·6665	·6829	·6993
58	·6341	·6500	·6671	·6835	·6999
60	·6346	·6511	·6676	·6840	·7004

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	41°	42°	43°	44°	45°
0′	·7004	·7167	·7330	·7492	·7654
2	·7010	·7173	·7335	·7498	·7659
4	·7015	·7178	·7341	·7503	·7664
6	·7020	·7184	·7346	·7508	·7670
8	·7026	·7189	·7352	·7514	·7675
10	·7031	·7195	·7357	·7519	·7681
12	·7037	·7200	·7362	·7524	·7686
14	·7042	·7205	·7368	·7530	·7691
16	·7048	·7211	·7373	·7535	·7697
18	·7053	·7216	·7379	·7541	·7702
20	·7059	·7222	·7384	·7546	·7707
22	·7064	·7227	·7390	·7551	·7713
24	·7069	·7232	·7395	·7557	·7718
26	·7075	·7238	·7400	·7562	·7723
28	·7080	·7243	·7406	·7568	·7729
30	·7086	·7249	·7411	·7573	·7734
32	·7091	·7254	·7417	·7578	·7740
34	·7097	·7260	·7422	·7584	·7745
36	·7102	·7265	·7427	·7589	·7750
38	·7108	·7270	·7433	·7595	·7756
40	·7113	·7276	·7438	·7600	·7761
42	·7118	·7281	·7443	·7605	·7766
44	·7124	·7287	·7449	·7611	·7772
46	·7129	·7292	·7454	·7616	·7777
48	·7135	·7298	·7460	·7621	·7782
50	·7140	·7303	·7465	·7627	·7788
52	·7146	·7308	·7471	·7632	·7793
54	·7151	·7314	·7476	·7638	·7799
56	·7156	·7319	·7481	·7643	·7804
58	·7162	·7325	·7487	·7648	·7809
60	·7167	·7330	·7492	·7654	·7815

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	46°	47°	48°	49°	50°
0′	·7815	·7975	·8135	·8294	·8452
2	·7820	·7980	·8140	·8299	·8458
4	·7825	·7986	·8145	·8304	·8463
6	·7831	·7991	·8151	·8310	·8468
8	·7836	·7996	·8156	·8315	·8473
10	·7841	·8002	·8161	·8320	·8479
12	·7847	·8007	·8167	·8326	·8484
14	·7852	·8012	·8172	·8331	·8489
16	·7857	·8018	·8177	·8336	·8495
18	·7863	·8023	·8183	·8341	·8500
20	·7868	·8028	·8188	·8347	·8505
22	·7873	·8034	·8193	·8352	·8510
24	·7879	·8039	·8198	·8357	·8516
26	·7884	·8044	·8204	·8363	·8521
28	·7890	·8050	·8209	·8368	·8526
30	·7895	·8055	·8214	·8373	·8531
32	·7900	·8060	·8220	·8378	·8537
34	·7906	·8066	·8225	·8384	·8542
36	·7911	·8071	·8230	·8389	·8547
38	·7916	·8076	·8236	·8394	·8552
40	·7922	·8082	·8241	·8400	·8558
42	·7927	·8087	·8246	·8405	·8563
44	·7932	·8092	·8251	·8410	·8568
46	·7938	·8098	·8257	·8415	·8573
48	·7943	·8103	·8262	·8421	·8579
50	·7948	·8108	·8267	·8426	·8584
52	·7954	·8113	·8273	·8431	·8589
54	·7959	·8119	·8278	·8437	·8594
56	·7964	·8124	·8283	·8442	·8600
58	·7970	·8129	·8289	·8447	·8605
60	·7975	·8135	·8294	·8452	·8610

Table of Chords, in Parts of a Radius 1; for Protracting *(continued)*.

M.	51°	52°	53°	54°	55°
0′	·8610	·8767	·8924	·9080	·9235
2	·8615	·8773	·8929	·9085	·9240
4	·8621	·8778	·8934	·9090	·9245
6	·8626	·8783	·8940	·9095	·9250
8	·8631	·8788	·8945	·9101	·9256
10	·8636	·8794	·8950	·9106	·9261
12	·8642	·8799	·8955	·9111	·9266
14	·8647	·8804	·8960	·9116	·9271
16	·8652	·8809	·8966	·9121	·9276
18	·8657	·8814	·8971	·9126	·9281
20	·8663	·8820	·8976	·9132	·9287
22	·8668	·8825	·8981	·9137	·9292
24	·8673	·8830	·8986	·9142	·9297
26	·8678	·8835	·8992	·9147	·9302
28	·8684	·8841	·8997	·9152	·9307
30	·8689	·8846	·9002	·9157	·9312
32	·8694	·8851	·9007	·9163	·9317
34	·8699	·8856	·9012	·9168	·9323
36	·8705	·8861	·9018	·9173	·9328
38	·8710	·8867	·9023	·9178	·9333
40	·8715	·8872	·9028	·9183	·9338
42	·8720	·8877	·9033	·9188	·9343
44	·8726	·8882	·9038	·9194	·9348
46	·8731	·8887	·9044	·9199	·9353
48	·8736	·8893	·9049	·9204	·9359
50	·8741	·8898	·9054	·9209	·9364
52	·8747	·8903	·9059	·9214	·9369
54	·8752	·8908	·9064	·9219	·9374
56	·8757	·8914	·9069	·9225	·9379
58	·8762	·8919	·9075	·9230	·9384
60	·8767	·8924	·9080	·9235	·9389

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	56°	57°	58°	59°	60°
0′	·9389	·9543	·9696	·9848	1·0000
2	·9395	·9548	·9701	·9854	1·0005
4	·9400	·9553	·9706	·9859	1·0010
6	·9405	·9559	·9711	·9864	1·0015
8	·9410	·9564	·9717	·9869	1·0020
10	·9415	·9569	·9722	·9874	1·0025
12	·9420	·9574	·9727	·9879	1·0030
14	·9425	·9579	·9732	·9884	1·0035
16	·9430	·9584	·9737	·9889	1·0040
18	·9436	·9589	·9742	·9894	1·0045
20	·9441	·9594	·9747	·9899	1·0050
22	·9446	·9599	·9752	·9904	1·0055
24	·9451	·9604	·9757	·9909	1·0060
26	·9456	·9610	·9762	·9914	1·0065
28	·9461	·9615	·9767	·9919	1·0070
30	·9466	·9620	·9772	·9924	1·0075
32	·9472	·9625	·9778	·9929	1·0080
34	·9477	·9630	·9783	·9934	1·0086
36	·9482	·9635	·9788	·9939	1·0091
38	·9487	·9640	·9793	·9945	1·0096
40	·9492	·9645	·9798	·9950	1·0101
42	·9497	·9650	·9803	·9955	1·0106
44	·9502	·9655	·9808	·9960	1·0111
46	·9507	·9661	·9813	·9965	1·0116
48	·9512	·9666	·9818	·9970	1·0121
50	·9518	·9671	·9823	·9975	1·0126
52	·9523	·9676	·9828	·9980	1·0131
54	·9528	·9681	·9833	·9985	1·0136
56	·9533	·9686	·9838	·9990	1·0141
58	·9538	·9691	·9843	·9995	1·0146
60	·9543	·9696	·9848	1·0000	1·0151

TABLE OF CHORDS, IN PARTS OF A RADIUS 1; FOR PROTRACTING (*continued*).

M.	61°	62°	63°	64°	65°
0′	1·0151	1·0301	1·0450	1·0598	1·0746
2	1·0156	1·0306	1·0455	1·0603	1·0751
4	1·0161	1·0311	1·0460	1·0608	1·0756
6	1·0166	1·0316	1·0465	1·0613	1·0761
8	1·0171	1·0321	1·0470	1·0618	1·0766
10	1·0176	1·0326	1·0475	1·0623	1·0771
12	1·0181	1·0331	1·0480	1·0628	1·0775
14	1·0186	1·0336	1·0485	1·0633	1·0780
16	1·0191	1·0341	1·0490	1·0638	1·0785
18	1·0196	1·0346	1·0495	1·0643	1·0790
20	1·0201	1·0351	1·0500	1·0648	1·0795
22	1·0206	1·0356	1·0504	1·0653	1·0800
24	1·0211	1·0361	1·0509	1·0658	1·0805
26	1·0216	1·0366	1·0514	1·0662	1·0810
28	1·0221	1·0370	1·0519	1·0667	1·0815
30	1·0226	1·0375	1·0524	1·0672	1·0820
32	1·0231	1·0380	1·0529	1·0677	1·0824
34	1·0236	1·0385	1·0534	1·0682	1·0829
36	1·0241	1·0390	1·0539	1·0687	1·0834
38	1·0246	1·0395	1·0544	1·0692	1·0839
40	1·0251	1·0400	1·0549	1·0697	1·0844
42	1·0256	1·0405	1·0554	1·0702	1·0849
44	1·0261	1·0410	1·0559	1·0707	1·0854
46	1·0266	1·0415	1·0564	1·0712	1·0859
48	1·0271	1·0420	1·0569	1·0717	1·0863
50	1·0276	1·0425	1·0574	1·0721	1·0868
52	1·0281	1·0430	1·0579	1·0726	1·0873
54	1·0286	1·0435	1·0584	1·0731	1·0878
56	1·0291	1·0440	1·0589	1·0736	1·0883
58	1·0296	1·0445	1·0593	1·0741	1·0888
60	1·0301	1·0450	1·0598	1·0746	1·0893

STADIA REDUCTIONS FOR READING 100 (*continued*).

Minutes.	12°		13°		14°		15°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0'	95·68	20·34	94·94	21·92	94·15	23·47	93·30	25·00
2	95·65	20·39	94·91	21·97	94·12	23·52	93·27	25·05
4	95·63	20·44	94·89	22·02	94·09	23·58	93·24	25·10
6	95·61	20·50	94·86	22·08	94·07	23·63	93·21	25·15
8	95·58	20·55	94·84	22·13	94·04	23·68	93·18	25·20
10	95·56	20·60	94·81	22·18	94·01	23·73	93·16	25·25
12	95·53	20·66	94·79	22·23	93·98	23·78	93·13	25·30
14	95·51	20·71	94·76	22·28	93·95	23·83	93·10	25·35
16	95·49	20·76	94·73	22·34	93·93	23·88	93·07	25·40
18	95·46	20·81	94·71	22·39	93·90	23·93	93·04	25·45
20	95·44	20·87	94·68	22·44	93·87	23·99	93·01	25·50
22	95·41	20·92	94·66	22·49	93·84	24·04	92·98	25·55
24	95·39	20·97	94·63	22·54	93·81	24·09	92·95	25·60
26	95·36	21·03	94·60	22·60	93·79	24·14	92·92	25·65
28	95·34	21·08	94·58	22·65	93·76	24·19	92·89	25·70
30	95·32	21·13	94·55	22·70	93·73	24·24	92·86	25·75
32	95·29	21·18	94·52	22·75	93·70	24·29	92·83	25·80
34	95·27	21·24	94·50	22·80	93·67	24·34	92·80	25·85
36	95·24	21·29	94·47	22·85	93·65	24·39	92·77	25·90
38	95·22	21·34	94·44	22·91	93·62	24·44	92·74	25·95
40	95·19	21·39	94·42	22·96	93·59	24·49	92·71	26·00
42	95·17	21·45	94·39	23·01	93·56	24·55	92·68	26·05
44	95·14	21·50	94·36	23·06	93·53	24·60	92·65	26·10
46	95·12	21·55	94·34	23·11	93·50	24·65	92·62	26·15
48	95·09	21·60	94·31	23·16	93·47	24·70	92·59	26·20
50	95·07	21·66	94·28	23·22	93·45	24·75	92·56	26·25
52	95·04	21·71	94·26	23·27	93·42	24·80	92·53	26·30
54	95·02	21·76	94·23	23·32	93·39	24·85	92·49	26·35
56	94·99	21·81	94·20	23·37	93·36	24·90	92·46	26·40
58	94·97	21·87	94·17	23·42	93·33	24·95	92·43	26·45
60	94·94	21·92	94·15	23·47	93·30	25·00	92·40	26·50
$c+f=$ ·75	·73	·16	·73	·17	·73	·19	·72	·20
$c+f=$ 1·00	·98	·22	·97	·23	·97	·25	·96	·27
$c+f=$ 1·25	1·22	·27	1·21	·29	1·21	·31	1·20	·34

STADIA REDUCTIONS FOR READING 100 (*continued*).

Minutes.	16°		17°		18°		19°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′	92·40	26·50	91·45	27·96	90·45	29·39	89·40	30·78
2	92·37	26·55	91·42	28·01	90·42	29·44	89·36	30·83
4	92·34	26·59	91·39	28·06	90·38	29·48	89·33	30·87
6	92·31	26·64	91·35	28·10	90·35	29·53	89·29	30·92
8	92·28	26·69	91·32	28·15	90·31	29·58	89·25	30·97
10	92·25	26·74	91·29	28·20	90·28	29·62	89·22	31·01
12	92·22	26·79	91·26	28·25	90·24	29·67	89·18	31·06
14	92·19	26·84	91·22	28·30	90·21	29·72	89·15	31·10
16	92·15	26·89	91·19	28·34	90·18	29·76	89·11	31·15
18	92·12	26·94	91·16	28·39	90·14	29·81	89·08	31·19
20	92·09	26·99	91·12	28·44	90·11	29·86	89·04	31·24
22	92·06	27·04	91·09	28·49	90·07	29·90	89·00	31·28
24	92·03	27·09	91·06	28·54	90·04	29·95	88·96	31·33
26	92·00	27·13	91·02	28·58	90·00	30·00	88·93	31·38
28	91·97	27·18	90·99	28·63	89·97	30·04	88·89	31·42
30	91·93	27·23	90·96	28·68	89·93	30·09	88·86	31·47
32	91·90	27·28	90·92	28·73	89·90	30·14	88·82	31·51
34	91·87	27·33	90·89	28·77	89·86	30·19	88·78	31·56
36	91·84	27·38	90·86	28·82	89·83	30·23	88·75	31·60
38	91·81	27·43	90·82	28·87	89·79	30·28	88·71	31·65
40	91·77	27·48	90·79	28·92	89·76	30·32	88·67	31·69
42	91·74	27·52	90·76	28·96	89·72	30·37	88·64	31·74
44	91·71	27·57	90·72	29·01	89·69	30·41	88·60	31·78
46	91·68	27·62	90·69	29·06	89·65	30·46	88·56	31·83
48	91·65	27·67	90·66	29·11	89·61	30·51	88·53	31·87
50	91·61	27·72	90·62	29·15	89·58	30·55	88·49	31·92
52	91·58	27·77	90·59	29·20	89·54	30·60	88·45	31·96
54	91·55	27·81	90·55	29·25	89·51	30·65	88·41	32·01
56	91·52	27·86	90·52	29·30	89·47	30·69	88·38	32·05
58	91·48	27·91	90·48	29·34	89·44	30·74	88·34	32·09
60	91·45	27·96	90·45	29·39	89·40	30·78	88·30	32·14
$c+f=$ ·75	·72	·21	·72	·23	·71	·24	·71	·25
$c+f=1·00$	·96	·28	·95	·30	·95	·32	·94	·33
$c+f=1·25$	1·20	·36	1·19	·38	1·19	·40	1·18	·42

Remarks.

$(c + f)$ is the fixed length, to be added to the distance measured by the stadia hairs, in the case of telescopes which are *not* provided with an anallatic lens.

c = distance from plumb line of instrument to the further outer lens of telescope.

f = the distance from this point to where the lines of sight through the stadia hairs cross each other.

The anallatic lens eliminates this correction.

The value $(c + f)$ is easily obtained by experiment for each particular instrument.

TABLE OF DEDUCTIONS OR ADDITIONS TO BE MADE PER 100 FEET, IN CHAINING OVER SLOPING GROUND. (*Trautwine.*)

Slope in Deg.	Deduct Feet.	Rise in 100 ft. hor.	Slope in Deg.	Deduct Feet.	Rise in 100 ft. hor.
¼	·001	·436	¼	1·596	18·08
½	·004	·873	½	1·675	18·53
¾	·009	1·309	¾	1·755	18·99
1	·015	1·746	11	1·837	19·44
¼	·024	2·182	¼	1·921	19·89
½	·034	2·619	½	2·008	20·35
¾	·047	3·055	¾	2·095	20·80
2	·061	3·492	12	2·185	21·26
¼	·077	3·929	¼	2·277	21·71
½	·095	4·366	½	2·370	22·17
¾	·115	4·803	¾	2·466	22·63
3	·137	5·241	13	2·563	23·09
¼	·161	5·678	¼	2·662	23·55
½	·187	6·116	½	2·763	24·01
¾	·214	6·554	¾	2·866	24·47
4	·244	6·993	14	2·970	24·93
¼	·275	7·431	¼	3·077	25·40
½	·308	7·870	½	3·185	25·86
¾	·343	8·309	¾	3·295	26·33
5	·381	8·749	15	3·407	26·79
¼	·420	9·189	¼	3·521	27·26
½	·460	9·629	½	3·637	27·73
¾	·503	10·07	¾	3·754	28·20
6	·548	10·51	16	3·874	28·67
¼	·594	10·95	¼	3·995	29·15
½	·643	11·39	½	4·118	29·62
¾	·693	11·84	¾	4·243	30·10
7	·745	12·28	17	4·370	30·57
¼	·800	12·72	¼	4·498	31·05
½	·856	13·17	½	4·628	31·53
¾	·913	13·61	¾	4·760	32·01
8	·973	14·05	18	4·894	32·49
¼	1·035	14·50	¼	5 030	32·98
½	1·098	14·95	½	5·168	33·46
¾	1·164	15·39	¾	5·307	33·95
9	1·231	15·84	19	5·448	34·43
¼	1·300	16·29	¼	5·591	34·92
½	1·371	16·73	½	5·736	35·41
¾	1·444	17·18	¾	5·882	35·90
10	1·519	17·63	20	6·031	36·40

GRADIENT TABLE.

(Trautwine.)

Vert.	Hor.	Ft. per Mile.	Deg.	Min.	Vert.	Hor.	Ft. per Mile.	Deg.	Min.
1 in	3·	1760·00	18	26	1 in	57·3	92·16	1	0
1 in	4·	1320·00	14	2	1 in	60·	88·00	0	57½
1 in	5·	1056·00	11	19	1 in	70·	75·43	0	49
1 in	6·	880·00	9	28	1 in	76·4	69·12	0	45
1 in	8·	660·00	7	8	1 in	80·	66·00	0	43
1 in	9·	588·66	6	20	1 in	90·	58·67	0	38
1 in	10·	528·00	5	43	1 in	100·	52·80	0	34
1 in	11·4	461·94	5	00	1 in	114·6	46·07	0	30
1 in	12·	440·00	4	46	1 in	125·	42·24	0	27⅔
1 in	14·3	369·23	4	00	1 in	150·	35·20	0	23
1 in	15·	352·00	3	49	1 in	175·	30·17	0	19⅔
1 in	19·1	276·73	3	00	1 in	200·	26·40	0	17
1 in	20·	264·00	2	52	1 in	229·2	23·04	0	15
1 in	23·1	229·04	2	30	1 in	250·	21·12	0	14
1 in	25·	211·20	2	17	1 in	300·	17·60	0	11⅓
1 in	28·6	184·36	2	00	1 in	343·9	15·35	0	10
1 in	30·	176·00	1	55	1 in	400·	13·20	0	8⅔
1 in	32·7	161·47	1	45	1 in	500·	10·56	0	7
1 in	35	150·86	1	38	1 in	600·	8·80	0	6
1 in	38·2	138·22	1	30	1 in	800·	6·60	0	4⅔
1 in	40·	132·00	1	26	1 in	1000·	5·28	0	3¾
1 in	45·8	115·29	1	15	1 in	3437·	1·54	0	1
1 in	50·	105·60	1	9	Level		0·00	0	0

SLOPES IN FEET PER 100 FEET HORIZONTAL.

(*Trautwine.*)

Rise in ft. per 100 ft. hor.	Length of Slope per 100 ft. hor.	Angle of Slope.		Rise in ft. per 100 ft. hor.	Length of Slope per 100 ft. hor.	Angle of Slope.	
	feet.	deg.	min.		feet.	deg.	min.
1	100·005	0	34·4	31	104·695	17	13·4
2	100·020	1	8·7	32	104·995	17	44·7
3	100·045	1	43·1	33	105·304	18	15·8
4	100·080	2	17·5	34	105·622	18	46·7
5	100·125	2	51·8	35	105·948	19	17
6	100·180	3	26·0	36	106·283	19	48
7	100·245	4	0·3	37	106·626	20	18
8	100·319	4	34·4	38	106·977	20	48
9	100·404	5	8·6	39	107·336	21	18
10	100·499	5	42·6	40	107·703	21	48
11	100·603	6	16·6	41	108·079	22	18
12	100·717	6	50·6	42	108·462	22	47
13	100·841	7	24·4	43	108·853	23	16
14	100·975	7	58·2	44	109·252	23	45
15	101·119	8	31·9	45	109·659	24	14
16	101·272	9	5·4	46	110·073	24	42
17	101·435	9	38·9	47	110·494	25	10
18	101·607	10	12·2	48	110·923	25	38
19	101·789	10	45·5	49	111·359	26	6
20	101·980	11	18·6	50	111·803	26	34
21	102·181	11	51·6	51	112·254	27	1
22	102·391	12	24·5	52	112·712	27	28
23	102·611	12	57·2	53	113·177	27	55
24	102·840	13	29·8	54	113·649	28	22
25	103·078	14	2·2	55	114·127	28	49
26	103·325	14	34·5	56	114·612	29	15
27	103·581	15	6·6	57	115·104	29	41
28	103·846	15	38·5	58	115·603	30	7
29	104·120	16	10·3	59	116·108	30	32
30	104·403	16	42·0	60	116·619	30	58

SLOPES IN FEET PER 100 FEET HORIZONTAL—*continued.*

Rise in ft. per 100 ft. hor.	Length of Slope per 100 ft. hor.	Angle of Slope.		Rise in ft. per 100 ft. hor.	Length of Slope per 100 ft. hor.	Angle of Slope.	
	feet.	deg.	min.		feet.	deg.	min.
61	117·137	31	23	82	129·321	39	21
62	117·661	31	48	83	129·958	39	42
63	118·191	32	13	84	130·599	40	2
64	118·727	32	37	85	131·244	40	22
65	119·269	33	1				
				86	131·894	40	42
66	119·817	33	25	87	132·548	41	1
67	120·370	33	49	88	133·207	41	21
68	120·930	34	13	89	133·869	41	40
69	121·495	34	36	90	134·536	41	59
70	122·066	35	0				
				91	135·207	42	18
71	122·642	35	23	92	135·882	42	37
72	123·223	35	45	93	136·561	42	55
73	123·810	36	8	94	137·244	43	14
74	124·403	36	30	95	137·931	43	32
75	125·000	36	52				
				96	138·622	43	50
76	125·603	37	14	97	139·316	44	8
77	126·210	37	36	98	140·014	44	25
78	126·823	37	57	99	140·716	44	43
79	127·440	38	19	100	141·421	45	00
80	128·062	38	40				
				101	142·130	45	17
81	128·690	39	1	102	142·843	45	34

Horiz. distance = inclined dist. × cosine ang. of inclination.
Inclined ,, = hor. dist. ÷ ,, ,, ,,
Vert. height = hor. dist. × tangent ,, ,,
or = inclined dist. × sine ,, ,,

GRADIENT-TELEMETER LEVEL.

WHILE this work was in the press, the Author communicated the suggested improvements to the instrument found in p. 106, to Mr. L. Casella, but in greater detail. The difficulty in the way of substituting a dial in lieu of existing prismatic compass, an instrument in the Author's opinion quite unsuited for precise work, was this. The upper portion of the Gradient Telemeter works on an inclined axis, hence horizontal motion cannot be restored. The ordinary dial box would not answer, owing to the great dip of the needle which remains horizontal while the graduated circle is inclined.

To obviate this, the Author suggested that the degree graduations be marked, not only on the upper surface of the dial but also vertically down the circular side of the well in which the needle plays, the numbering being outside on the edge. No matter how much the compass box is inclined, the horizontal needle will then point to the graduations projected vertically down the side.

Mr. L. Casella together with the Patentee, held a sort of conference on the subject of all those suggestions, and, as will be seen in the following Report, agreed with every item excepting the adoption of the Hoffmann head, and will reconstruct the instrument on these lines. Cost 30*l.*; with vertically adjustable tube to tripod, 31*l.* 16*s.*

Report respecting the Construction of a Patent Gradient-Telemeter Level, with modifications of the existing patterns, as suggested by Mr. Bligh.

1. The whole of the suggestions are very explicit, and can readily be carried out, and also will add greatly to the usefulness of the instrument both for general field work as well as

for underground-mining work. Respecting the compass ring, about 5 inches diameter, to be fitted into the "well" of the compass box, this can easily be done, the graduations to be vertical, and on the inner face of the ring, (to single degrees), and the numbers for the vertical graduations to be on upper face of the ring; this is all very simple and efficient, and can readily be carried out. This will then give a long and strong needle about $4\frac{1}{2}$ inches in length, hence very sensitive.

2. The fixed horizontal dial or limb of the instrument will be similar to the limb of the "Mining Dial" lately had on trial, with this difference, that the graduations for the horizontal angles (as with a theodolite) will be on the *outer* part of this limb or dial, while the graduations which give the gradient readings will be on the *inner* part of the limb. This reverses the position they stand in, on the limb of the Mining Dial lately had on trial.

But there is no difficulty whatever in constructing the limb by this method. It is also clearly understood that this limb or circle is to be *fixed*; i.e. that part of the bevelled edge which carries the graduations showing the gradients, is to be solid with, and cast with that part of the same edge or face, which carries the graduations showing the *horizontal angles* as in a theodolite.

3. The telescope arrangement as suggested is also very clear—the telescope is to be somewhat *higher* above the compass plate than in the two instruments lately had on trial, this will enable the compass needle and vertical graduations on compass ring to be more easily read. The construction and fitting up of the telescope and its large spirit-level will be almost identical with that of the gradient level lately tested, and it will be made to reverse in its Y-bearings as a "RISE" or a "FALL" is being worked.

4. The three levelling screw and tribrach arrangements, as in the two instruments, will be still adhered to, rather than using or bringing in a "Hoffmann" head.

The vertically adjustable head can then be easily adapted to the tribrach base as suggested in the notes, on the lines of the printed illustration of this vertically adjustable head at pages 65 and 66 of the printed matter forwarded to us.

This vertically adjustable head will adapt *most readily* to the head of the mahogany stands of the two instruments lately on trial, and will add very little to the cost. A strong metal socket with clamp screw can be screwed on to the nose of the metal head of the stand, and a strong stout brass tube, about 1 foot long, will slide in the socket which is screwed on to the nose of the metal stand head.

ADJUSTMENT OF THE AUTHOR'S NEW INSTRUMENTS.

PLANTER'S ROAD TRACER, FIG. 31.

1. To test the horizontality of line of sight.

Set up instrument anywhere. Drive one peg within nine or twelve inches of the post, and another about 50 or 100 feet distant.

By means of a spirit level, or surveyor's level and staff, make the second peg exactly the same level as the first. Then place an ordinary ten-foot rod, or a level staff, on the first peg, and, looking through the sights, note the exact height on the staff intersected by the wire of the fore-sight; in case of ten-foot rod, this can best be marked by lightly nailing a cross piece of wood on to the rod. Next remove the rod or staff to the distant peg, and sight with the instrument. If the wire intersects the same spot or reading, the instrument is in correct adjustment; but if not, one of the two suspended weights will have to be increased or diminished in weight until the wire cuts the same point on the staff on both pegs. If the instrument reads high, the further suspended weight will have to be increased; if low, the *near* weight.

The exact amount of additional weight required can be ascertained, by suspending a few iron screws or nails, by means of a cotton thread hung from the clamp screw head at the bottom of weight to be increased. These can be increased or diminished in number, as required, till the two readings correspond. During these operations the cross vane temporarily attached to the rod used will require to be slightly altered in level with each variation in the inclination of the instrument. When the instrument is absolutely in adjustment—the adjusting weight can be added on

permanently by tapping in the side or bottom of the weight, and inserting a small brass coach screw, the projecting head of which should equal in weight the temporary load applied, allowance being made for increased leverage, if the screw is tapped in the side and not in bottom of the weight.

This adjustment can be made in a large room, or any place presenting a duly flat surface.

Reducing one of the suspended weights can best be performed by boring a wide conical hole in one, and increasing its size by degrees till the necessary reduction is effected.

This adjustment should be made with precision by the makers.

2. To determine height of T staff.

Set up on a level floor, and with the instrument horizontal, i.e. weight at extremities of bar, sight the T staff, which should be reduced or increased in length till the wire of the fore sight accurately coincides with the top edge of cross bar.

This instrument has now been fitted by Mr. Harling, the maker, with a centered antifriction joint in place of the plain pivot, which gives excellent results, the friction being inappreciable, and the precision of the instrument being effectively secured.

ADJUSTMENTS OF THE CONTOUR LEVEL AND CLINOMETER, FIGS. 41 AND 42.

1. The adjustments of the telescope are the same as those for a Y level and will not be dealt with.

2. To test correctness of adjustment of fixed level on lower plate.

After levelling by the parallel plate screws, reverse instrument, when the bubble should still remain in the centre of its run.

The adjustment of this point, if incorrect, can only be effected by the instrument maker.

The level on the telescope and that on lower plate should closely correspond.

3. To test the agreement of level of the two lines of plain sight.

Place a level staff on a peg about 25 feet from the instrument, pull out one pair of sights, and note reading. Then reverse instrument, and read staff with the other pair. The reading of both should be identical. The jaw should of course be closed down.

The correction required, if any, can only be done by the maker.

4. To test the parallelism of the two lines of plain sight to the lower plate and to the telescope—that is, their horizontality when the upper plate is closed down.

The procedure in this case is exactly similar to that already described for the " Planter's Road Tracer " (*vide ante*).

5. To ascertain difference of level of telescope and plain sights.

Place a level staff as near the instrument as can be read by the telescope, and read the staff by it and also by one pair of plain sights; the difference will give the shortening of the drop chain, required when the telescope is used.

6. To adjust the chain to length of T staff. (Any convenient length can be taken for the T staff, 4 feet or 4 feet 6 inches, according to height of observer)

Set and level up the insrument with disc of drop chain resting on a peg. Another peg should be put in some 20 feet off, exactly level with the former. Place the T staff on this, and raise or lower instrument by the sliding tube, till the cross-wire of telescope coincides exactly with top of T staff. Then adjust length of chain so that the disc just touches the first peg.

The chain will be made for a fixed height of T staff (viz. 4 feet: the operation above described will be a check on the accuracy of length of chain, which is made adjustable in length.

The chain shown in Figs. 41 and 42 has since been improved in design. A square brass loop hangs below the back

hinge of the instrument, to the pivot of which it is attached. The chain, which is of closer make than in the illustration, is hooked on to this. Half-way down the chain a sliding adjustment is fixed, which is graduated for the telescope and plain sight reading respectively. This enables the chain to be shortened, the exact difference between the two lines of sight. It is further graduated with marks to allow for the difference between the vertical height of line of sight above lower plate, and the incline height when the jaws are opened. In the flatter slopes this difference is hardly appreciable, but in the grosser ones allowance in length of drop chain will necessarily have to be made to ensure absolute precision.

The whole chain is likewise adjustable in length to a nicety, by a screw working into the disc at bottom, and provided with a key nut.

ADJUSTMENTS OF THE PRISMATIC DIAL AND CLINOMETER, FIGS. 5 AND 6.

1. Vertical line of sight.

After levelling up, set the compass by reading the prism exactly at the zero point of the ring.

Then place a rod a long distance off, so that it is intersected by the fore-hair of the sights. Now revolve the instrument 180,° and if the rod is again intersected by the second pair of sights, the adjustment is exact; if not, either the sight vanes are not properly vertical, or else the pin reader inside the compass box is not in the correct position.

It can be slightly shifted, as required, by removing the glass and loosening the clamp screws which fix its base to the side of the box.

This adjustment should be made by an instrument maker, as it is difficult to effect.

The verticality of the sights can be roughly tested by sighting a free suspended cord or thread with weight attached to its extremity.

2. Horizontal line of sight.

The test of the parallelism of the horizontal sight to the base of instrument, is effected precisely as already described for the "Planter's Road Tracer" page 214, viz. by placing a staff or rod with vane on two levelled pegs, one as close as possible to the instrument, and the other as far off as can be well seen.

If the reading is the same at both pegs, the instrument is in adjustment; if not, the necessary alterations will have to be effected by the maker.

This instrument should properly be mounted on a Hoffmann head as in Fig. 41.

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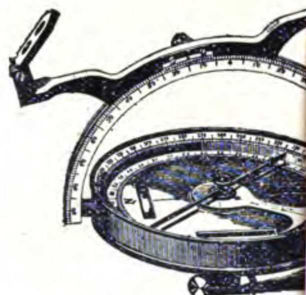

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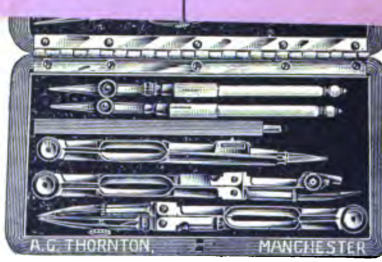

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